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Medal for Student Members. A medal and a prize of five guineas will be awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented a paper of outstanding merit during the session.

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FIRST EMPIRE MINING AND METALLURGICAL CONGRESS.

THIS Conference was convened by the Institutions of Mining and Metallurgy, Mining Engineers, Petroleum Technologists, the Mining Association of Great Britain, the Iron and Steel Institute, the Institute of Metals, and the National Federation of Iron and Steel Manufacturers, in connection with the British Empire Exhibition, 1924, and took place from June 3rd to June 6th, 1924, in the Conference Halls at Wembley. It was divided into four sections—A, Mining; B, Petroleum; C, Metallurgy of Iron and Steel; and D, Non-Ferrous Metallurgy—and

the papers read before Section B, and the discussions thereon, are published in this Journal. Time did not permit of the papers being read in full, and in the majority of cases they were briefly introduced by their authors and taken as read.

The first day of the Congress, Tuesday, was occupied with an address by the President, the Rt. Hon. Viscount Long of Wraxall, P.C., F.R.S., and a visit to the Mineral Exhibits, etc.

On Wednesday and Thursday the various sections held their own meetings, and on Friday the concluding General Session took place.

In addition to the Congress Meetings, several functions took place in London, as follows :—

Reception at the Imperial College.—On Tuesday, June 3rd, 1924, the Rector of the Imperial College of Science and Technology, and Lady Holland were At Home at 8.30 p.m. at the Royal School of Mines to the Overseas Delegates and Members of the Congress and their ladies. During the evening interesting exhibits in connection with Mining, Metallurgy, and Petroleum Technology were shown and demonstrated.

Official Banquet at the Guildhall.—On Thursday, June 5th, 1924, the President of the Congress, supported by the Presidents of the convening bodies, presided at the Official Banquet at the Guildhall (by courtesy of the Corporation of the City of London) to meet His Royal Highness the Prince Arthur of Connaught, K.G., K.T., and the Official Delegates and Members from Overseas.

Reception at Goldsmiths' Hall.—On Friday afternoon, June 6th, 1924, the Wardens and Court of the Goldsmiths' Company received the Official Delegates and Overseas Members and their ladies at the Goldsmiths' Hall.

No. 44. Vol. 10.

EMPIRE MINING & METALLURGICAL CONGRESS

LONDON, JUNE 3—6, 1924.

Section B: Petroleum.

Wednesday, June 4th, 1924, at 10.30 a.m.

Mr. Herbert Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A., M.Inst.Mar.Eng., President of the Institution of Petroleum Technologists, in the Chair.

The Chairman, at the opening of the Meeting, said he desired, at the first Session of the Section, to take the opportunity, on behalf of the Institution of Petroleum Technologists, of extending a very hearty welcome to the visitors, many of whom had come to England from long distances. He was sure the meetings would be of mutual benefit to all concerned, and that the exchange of ideas would be very helpful. The papers embraced a considerable number of subjects, including the Economics of the Oil Industry, Petroleum Geology, Petroleum Drilling, Petroleum Engineering, The Crude Oils of the Empire, The Refining of Oil-Shale, Oil Transport, and The Bulk Distribution of Oil. In some cases the papers would be taken as read and briefly introduced by the authors, but the first paper on the Economics of the Oil Industry was such an important one that he proposed to ask Sir Robert Waley-Cohen to read it practically in full, as it would lose value by curtailment.

The Economics of the Oil Industry.

By Sir Robert Waley-Cohen, K.B.E.

It is with great diffidence that I accepted the invitation of this Congress to address you on the subject of "The Economics of the Oil Industry." I am not an economist, but a person who sits at a desk watching the operation in the oil industry of those relentless forces which govern all industry and which economists are accustomed to elucidate for our benefit with conclusions which are not always unanimous.

As a result of your invitation, in an endeavour to prepare myself for the present occasion, I have been reading some works on economics. They press home upon one rather a depressing conclusion, which ought perhaps to have been present to one's

mind before. I only record it to-day because I think that if it is right—and I do not doubt that it is—it is a conclusion which is of the greatest importance, and that if it can be absorbed by the mass of the consuming population it will do something to save us from kicking against the spurs of economic forces, which, as many of us have experienced during the last ten years, is a very painful process. The conclusion is that we who are engaged in industry and are sometimes prone to imagine that we exercise some effect upon the wealth of the community, are really nothing more than cockle-shells tossed about upon a sea of great economic forces which we can do, and do do, very little to influence. When, for instance, the price of petrol goes up I very often read in the papers that it is due to some artificial decision of a Trust or to some dark and powerful human agency. I have even seen my own portrait in the newspaper on such an occasion. Those who study the economics are aware that that move may have been postponed or advanced by a few weeks by the operation of some human mind, but that, except for some very small consideration of that sort, that move in price has followed, as surely as the day follows night, an increase in demand or a diminution in supply either in the world's requirements of that commodity itself or in the world's requirements of the means of bringing it from existing sources of supply to the consumer's door.

Recent schools of economists are inclined, I believe, to prove to us that in most commodities an anticipatory curve can be drawn showing how prices are going to go up and down over cycles of years ahead. In these cases the business man, whether he be part of a great organisation or merely an individual struggling unit, must feel painfully conscious of the passive part he is really playing. In oil, however, such curves can certainly not be drawn. It may be possible to predict years of world prosperity when demand will be greater than in lean years, but nobody can say what will happen in regard to supply. No one can foretell the date when some one or other of the innumerable wild-cat wells that are constantly going down will strike a new field that may flood the markets of the world with quantities exceeding expectations by an amount of such an entirely different order from the variations in demand as to swamp them entirely. That experience happened a year ago when a new field was suddenly struck and feverishly developed by countless rival interests, and it has happened at irregular intervals throughout the whole history of the oil business. All that the great organisations can do is, by their close attention to what is going on, to move rapidly in response to the changes in supply and demand, so that they may protect the consumer to some extent and mitigate the violence of these inevitable fluctuations. At the moment, for instance, we know that there has been a large fall in the production

of at least two of the large oilfields which contribute more largely than any others to the supply of fuel oil. Early signs of the approach of this situation became apparent some months ago and prices were raised, with the result that those consumers who were least dependent upon oil went over to coal, thus setting free supplies for those who needed it more. The shrinkage continued to develop, and prices were raised again, until to-day throughout the world liquid fuel prices are at a level at which many of those who were using it for steam raising have temporarily abandoned its use. The waste which was going on has thus been automatically stopped and the oil resources of the world thus preserved for Diesel engines, passenger steamships and others to whom the use of oil is a necessity, or an economy so great that even though the disparity between coal and oil prices were to be largely increased, they would still continue to use oil.

To-day there are peeping out indications that the ceaseless search for new fields is going to meet with success in one or two new directions. Liquid fuel prices have ceased to rise, and if the early hopes prove justified it will soon be possible to effect some reduction and to spare supplies again for those who are glad to use oil fuel on account of its great economy and convenience, but to whom it is not an absolute necessity. If the rise in fuel prices had been postponed until it became obvious that there were no supplies, the dislocation in trade resulting from the inability to meet requirements would have been far greater, and the restoration to a normal situation might easily have been postponed until a much later stage when, owing to the unduly prolonged period of high prices, large avenues of possible outlet would have been permanently closed and we might see a flood of supplies which could find no outlet and which would again give rise to irretrievable waste with a sharp reaction to follow. Moreover, before the new supplies could be used, someone would have to pay for the entirely wasted cost of consumers' conversion to coal and back again to oil.

I have given all this merely as an illustration of the service which I think, notwithstanding the inexorable play of economic forces, the great oil organisations can and do render to the consumers of oil products in the world. Apart from this fundamental economic service they also, I think, have been able to produce in the short span of sixty years, which covers the whole period of the existence of the oil industry, a state of organisation and a breadth of distribution such as the older industries have taken centuries to achieve. The motor industry may be said almost to have revolutionised our civilisation. It has made it possible for the accumulated town populations, grown up since the industrial revolution, to enjoy fresh air and healthy recreation to a degree which could never have

been dreamt of without it, and it has exercised a considerable influence in keeping rural populations on the land. This industry could never have been created but for the highly organised system of distribution, which the great oil concerns started developing some twenty years ago and on which they have since expended millions of capital and much highly skilled energy. Distribution and transport of petroleum products on the scale which has become necessary to the populations of the world can only be undertaken by large organisations which have behind them resources of supply, not only great in themselves, but so widespread in their distribution as to be comparatively independent of changes in any single field. Production, except in established regions of supply, where the element of experiment has to a large extent been eliminated, can only be achieved on any large scale by those to whom even a costly and expensive failure in one field represents a small part of their total operations. Thus in accepting your invitation to go up in an aeroplane, so to speak, and take a bird's eye view of the oil industry, I have been impressed more than ever with the vital value to the industry itself (and thus indirectly to the whole gamut of the world's activities at the present day) that must be attributed to the concentration which has been so prominent a feature of the oil industry.

These are the outstanding facts of the economics of the oil industry, but as I myself have neither the leisure nor the knowledge to undertake such a detailed examination as you are entitled to expect, I have sought the co-operation of one of the authors of a recent remarkable book upon the oil industry which bears the curious title, "The Oil Trusts and Anglo-American Relations." There is a good deal in that book with which I do not agree, but its authors seem to me to have been almost the first to attempt to co-ordinate and survey the broad present-day facts of the oil industry, and I, therefore, felt myself to be very fortunate when Mr. Davenport consented to assist me in this paper by supplying me with some statistics as to oil price cycles and some of the substance of the survey which I am now proposing to put before you.

Oil price cycles, which may be measured from one point of maximum prices to the next or from one point of minimum prices to the next, show unmistakably that the oscillations in the oil trade as in other trades result from the operation of the law of supply and demand to which I have alluded. Analysing it further, if you will, you will find that oscillations in trade, credit or prices are set up or are kept in motion by the play of three general forces—the psychological, comprising the peculiar alternations from optimism and depression in the individual man, his competitive instincts, his habits, his ignorance and his lapses from good judgment; the natural, comprising the forces of nature, the failure or success of

crops, the discoveries or disappointments in mining, as well as earthquakes, floods and the like ; the political, comprising the restrictions on trade imposed by political man, his strikes, revolutions, wars, not forgetting his wilful depreciation of currency, his good or bad credit system. And yet there are critics of the oil industry who do not cease plaintively to cry that oil prices are fixed by the wickedness of what they call oil combines.

The analysis of the history of the oil business shows that, as in the case of other commodities, oil prices are determined by the division of the volume of the oil commodity by the volume of purchasing power, and that the only difference between oil price cycles and those of other commodities is that the oscillations in the case of crude oil are more frequent and more extreme.

It should be stated at the outset that neither the price of crude oil nor the price of a refined oil bears the same systematic relationship to the cost of production as is the case with ordinary commodities. The normal tendency is for the price or value of a commodity to correspond with what is called its marginal cost of production—that is, with the " cost of production of that part of the annual output which is wrested with most difficulty from the lap of nature." In the case of crude oil, the producer has to take into account certain indirect and non-tangible elements in order to arrive at the real marginal cost of production. An American economist has given the following analysis of the operating costs of a representative company in the Mid-Continent field : direct lifting expense 22·5 per cent., depletion of property 18·5 per cent., depreciation of physical equipment 15·6 per cent., non-tangible development expense 14·55 per cent., dry holes and abandonments 13·2 per cent., general expense 6·4 per cent., year's proportion of bonus 5·13 per cent., rentals of undeveloped acreage 4·12 per cent. Of course, these proportions vary enormously in different fields. For instance, most of the £8,000,000 spent some fifteen years ago in the endeavour to develop an oilfield at Maikop in Russia was completely lost, as the field proved to be of no commercial value. The experience gained was no doubt great, has been of value to those who undertook the experiment, and may assist very largely in diminishing the costs of repeating the same experiments in other fields ; but the failure in Maikop must be regarded as part of the cost of developing oil production in other fields that have profited by the experience gained in Maikop. And similarly every great oil organisation is constantly making costly experiments in the search for oil, the expense of which must be charged to their general operations if they are to show an ultimate profit and thus to receive the confidence necessary to secure the capital without which the industry could not be carried on.

But even apart from these large and incalculable sums, which

would have to be taken into account in any attempt to estimate the cost of oil production, there are smaller variations which render any such calculation futile. In a gushing well the direct lifting expense may be practically nil, whilst there are deep wells which require pumping in which the lifting expenses are put as high as 72 cents a barrel. I have seen it stated that in Mexico last year 50 per cent. of the wells bored proved to be dry holes, and seeing that some of the experimental holes cost as much as $150,000 each, it is easy to see what a large proportion of the cost of the total production in Mexico must be borne by unsuccessful experimental drilling. But apart from these violent fluctuations in costs of operations, the fluctuations in supply resulting from large discoveries from time to time are so great as to make the price of crude oil a thing which is in reality governed by the relation of supply to demand and is almost independent of any *fixed* relationship to the marginal cost of production.

Similarly, the prices of refined oils bear no systematic relation to the marginal costs of manufacture. The products which a refiner may obtain from the stills vary greatly according to the composition of the crude oil and the method of refining. Where fluctuations are so great it is, perhaps, a questionable expedient to utilise averages at all. However, the following figures may give some indication. (I should here state that throughout this paper I have used indiscriminately the American word "gasoline" and its English equivalent "petrol.") An average barrel of American crude oil has been said to yield at present 46 per cent. of gas and fuel oil, 27 per cent. of gasoline, 10 per cent. of kerosene, 4 per cent. of lubricating oil and varying quantities of paraffin wax, asphalt, etc. Even if the economic focus of the refinery be the production of gasoline, all the other products have to be manufactured at the same time, and some of them usually have to be sold at a "loss," that is, at prices under the marginal cost of production, if that cost be distributed among them according to the percentage of their yield from the crude oil. Hence gasoline as a rule has at present to bear a price which will return much more than its proportion of the total receipts from the barrel of the crude oil. It has sometimes been said that gasoline receipts pay for the cost of the crude oil, that kerosene receipts pay for the cost of refining, that fuel oil receipts pay for the cost of marketing and that receipts for lubricating oil are left for profit. But no such division has really any meaning. As is well known, there are crude oils which yield no gasoline; there are many crude oils which yield no lubricating oil, and there are others which yield no kerosene. The fact is that the relative prices of gasoline, kerosene, fuel oil and lubricating oil are themselves merely expressions of the result of the operation of supply and demand. Compared, for instance, with the average

price of gasoline to-day, the cost of refining most gasolines is almost negligible. The products contained in the crude oil all come out of the ground together, and the only difference in their *cost* is the refining cost. Why, then, is petrol sold at say £20 a ton and fuel oil at say £4 a ton? It is merely that the relation between the demand and the supply of petrol and its value to the consumer is such that it can and does pay a much higher proportion of the cost of the crude oil than the proportion in which it is actually contained in the crude oil as it comes out of the ground. In the oil business nothing is so dangerous as to indulge in prophecy, but if the development of the Diesel engine, or some other development that is yet in its infancy or not yet discovered, should make the demand for fuel oil in relation to its supply greater than that for petrol, then there is no reason why fuel oil should not be £20 a ton and petrol £4 a ton. The only fixed ultimate constant which cannot change is that in the long run the prices realisable for the whole of the products of the crude must be such that, taken together, they cover the cost of the crude and of manufacturing and transporting the products to the consumer. If the economic focus of the refinery shifted to the production of fuel oil, petrol might become a drug on the market if, in order to meet the world's requirements of fuel oil, quantities of petrol were produced in excess of the world's requirements. Under such circumstances fuel oil receipts might have to account for 90 per cent. of the total and petrol for perhaps only 5 per cent. Some twenty-five years ago anyone passing the coast of Sumatra could have seen a large column of smoke ascending to the heavens. That represented the costly process of pumping petrol out into the jungle and burning it at such a distance from civilisation as to do no harm to anyone. It was unsaleable at any price. The crude oil was produced then mainly for the sake of the kerosene which it contained, and the kerosene was sold at such a price as to cover the whole cost of the production and refining of the crude oil. Thus it will be appreciated that the price of a refined oil bears little or no relation to the proportionate cost of the production of the crude oil. That fixed or systematic relation of price to marginal cost of production, which is the rule in the economic world generally, is certainly non-existent in regard to oil.

An analysis of some oil price cycles will elucidate the point that the oscillations in the prices of crude oil are more extreme than in those of all commodities averaged and are much more extreme than in those of gasoline. As American oil prices have been generally regarded as governing world oil prices, and still do so to a large extent, we will take for illustration the index numbers of the weighted averages of five different American crude oils (Pennsylvania, Illinois, Mid-Continent, Gulf and California) as

published in Pogue's "Economics of Petroleum" for the period 1913 to August, 1921; thereafter to January, 1924, we have had to take the index numbers of Kansas-Oklahoma crude oil as published by the U.S. Department of Commerce. For gasoline and all commodities we have been able to use the index numbers of the U.S. Department of Commerce and Bureau of Labour over the whole period from 1913 to January, 1924. In all cases the average of 1913 has been taken as 100. The chart which accompanies this paper will show at a glance the violent oscillations in the case of crude oil, as compared with all commodities and with gasoline. For convenience I will summarise the differences here, measuring the amplitude of the price wave from bottom to crest and from crest to bottom in percentages from the 1913 average.

(1) *Price cycle* 1913 *to July*, 1915:—

Crude oil went up 8 points and down 53.
Gasoline „ 4 „ „ 38.
All commodities „ 4 „ „ 3.

This cycle shows very definitely the extreme violence of the oil oscillation. It covered the period of the Cushing depression. The strengthening markets of 1913 had stimulated a country-wide drilling campaign. Suddenly the deep sands of the Cushing pool in Oklahoma were struck in April, 1914. Production went wild; oil poured forth from a multitude of wells drilled in frenzied haste. The bottom dropped out of the crude oil market. The Cushing surplus was one of the greatest the oil industry has ever experienced. It is difficult to know what would have happened to all this oil if it had not been that the war broke out at this moment and the fleets of the world were mobilised and required almost limitless quantities of fuel oil. It may be of interest to reflect that if it had not been for the Cushing pool it is doubtful whether the British Fleet could have secured its requirements of fuel oil during the second half of 1914. To the oil industry in America the demand of the British Fleet at this moment of unprecedented flood was salvation. It would perhaps have been of greater interest to the conomist if this salvation had not appeared and there had been an opportunity of observing the effects of a situation which would have been unique in the history of the oil business.

(2) *Price cycle of July*, 1915, *to September*, 1916, *for crude oil to December*, 1916, *for gasoline*:—

Crude oil went up 75 points and down 29.
Gasoline „ 63 „ „ 15.
All commodities went on rising (from 101 to 146).

This cycle illustrates the suddenness, as well as the violence, of oil price fluctuations. All commodities kept on rising. The demands of war had removed the surplus of Cushing crude and oil prices had risen for ten months. In America the oil business is a

national industry. There are very large numbers of men who watch the market and who at favourable moments undertake speculative drilling operations. These ten months of continual rise caused a multiplication of such operations. A considerable proportion of them were successful, and the result was over-production in the Mid-Continent fields, which caused a sharp reaction in price, arising not so much from the discovery of any notable new field as from the excessively rapid development of existing fields. Such a reaction could not fail to have an inevitable Nemesis.

(3) *Price cycle September or December*, 1916, *to April*, 1919 :—

Crude oil went up 103 points and down 12.
Gasoline „ 30 „ „ 2.
All commodities went on rising (146 to 203).

The upward wave of this price cycle was abnormally sustained, partly under the pressure of increasing war demands and partly from over-rapid depletion due to the over-rapid development referred to in cycle (2). The effects of these forces culminated in September, 1918, after which a measure of price stabilisation was put into effect by voluntary co-operation between the industry and the American Government. Whether such an arrangement could have lasted for any length of time is, to my mind, very doubtful. If the stabilised price was a profitable one the oil speculators in these highly divided territories would have drilled feverishly against one another in order that they and not their neighbours might secure such oil as was in the ground. The result would have been exhaustion of supplies, and nothing but such a rise in price as would make it profitable to take heavy risks in wild-catting in unproved territories could be expected to maintain supplies. If, on the other hand, the price was unprofitable, boring would have ceased and the existing fields, though lasting for a longer time, would sooner or later have given out, and the failure to maintain the normal drilling in new fields would have resulted in a long-drawn crisis of short supplies. However, the war came to an end, the demand for fuel oil for the Fleets, which had been of such colossal dimensions, suddenly disappeared, and in 1919 the price of the heavy crude oils consequently dropped rapidly, whilst that of the light crude oils remained more or less stationary.

(4) *Price cycle April* 1919 *to August* 1921 *for crude, to September* 1921 *for gasoline* :—

Crude oil went up 122 points and down 204
Gasoline „ „ 38 „ „ „ 56
All commodities rose to 272 and fell down 131.

The 1920 boom is too familiar for description. From all over the world there flowed demands for oil products which exceeded the

ability of producers and refiners to meet them. There had been a shortage of boring material and this contributed to a diminished drilling, which aggravated the existing tendency. Under the stimulus of soaring prices supply attempted to catch up with demand. Thus the crude oil index number went up 122 points as against a rise of 46 points for all commodities over the same period: so mountainous was the oil price wave. Then suddenly demand stopped. Various sparks exploded the balloon of inflation. There was the Chinese boycott of Japanese goods: there was the consumers' strike in America. The causes which combined to produce deflation in other commodities had their immediate effect in the oil business. Merchants found that they had grossly miscalculated. The industry found itself overstocked and over-equipped. Prices fell like a stone to readjust the balance between demand and supply. Crude oil fell 204 points and all commodities 131 points. This cycle shows up gasoline prices in a very favourable light. The gasoline index number only went up 38 and fell 56, showing a large degree of stabilisation. And the peak was only 180 as against 272 for all commodities, indicating that gasoline was much cheaper in the boom period than the average commodity. I think this cycle illustrates perhaps more than any other the effect of the great oil organisations—which are sometimes called "Oil Combines," but not for any particular reason that I have been able to discover, as the combination of independent elements is not in any way characteristic of their constitution. During this boom period I used frequently to be discussing with officials of the Board of Trade the so-called high petrol prices, and I analysed for their benefit the whole of the factors which seemed to me to contribute to create the price from time to time. The effect was always that I was unable to explain why the prices were not very much higher than they actually were. The real reason was that the great oil organisations were using the whole of their resources to keep the price down to the lowest possible level consistent with the high costs of oil and of transport ruling at the time. But that was not at the time a popular theory. For months products were sold at far below the figure at which they could have been bought and transported to the consumer, in the hope that the costs would fall and would eventually justify the resistance to the unrestricted forces of the moment. This policy was, of course, dictated by an enlightened and broadly conceived self-interest. Nothing could be so serious to the great oil organisations as that prices of their commodities should go up to such a figure as to drive off consumers and so diminish the value of the great distributing organisations which have been built up at such enormous cost. And so prices of petrol were kept down, and the policy was eventually justified by a fall in the cost of replacement.

(5) *Price cycle, September,* 1921, *to December,* 1922 (*to January,* 1923, *for gasoline*)—

Crude oil went up 134 points and down 107
Gasoline „ „ 27 „ „ „ 27
All commodities went on rising (141 to 156).

This cycle again shows up gasoline prices in a favourable light. The extreme oscillations in the wave of crude oil prices were due to miscalculation both of demand and supply—there was a sudden increase in consumption in December, 1921, and there was talk of the exhaustion of both Mexican and American fields which encouraged speculative drilling.

(6) *Price cycle, December,* 1922, *to December,* 1923:—

Crude oil went up 64 points and down 89
Gasoline „ „ 8 „ „ „ 48
All commodities went up 3 points and down 8.

The upward wave in this price cycle started again from the expectation of a shortage of supply to meet an increased demand, but was short-lived. The organisation to which I have the honour to belong had discovered an entirely new field in Southern California situated in an area which was in the neighbourhood of a town and, therefore, infinitely sub-divided among small owners. About the same time the Texas fields were being developed and the flood of oil which poured forth from all these fields quickly upset the balance and created a large over-supply of oil. To some extent the effect on the world markets was less than it might have been owing to the distance of the Californian fields. This meant that three times as much ocean tonnage was required to carry the same quantity of oil to the consuming markets as would have been necessary from the old fields. Thus there arose an enormous demand for tank steamers, and freights went up to a very high level, diminishing to some extent the effect of the cheap supplies available in California. However, these new Californian fields passed their peak of production in August, and the principal Texas field in November, the total daily average production for the whole of America reaching its zenith of 2,280,000 barrels in the week ending September 8th. Consumption had steadily increased so that by the end of the year the downward wave of crude oil prices was stopped. In this cycle the fall in gasoline prices was unduly severe for peculiar reasons. The over-production of a light grade of crude oil in California had caused a disproportionate over-production of gasoline, and in the general liquidation which followed, a price-cutting war was started and spread throughout practically the whole world. In December the gasoline index number stood at 84 as against 151 for all commodities, showing the gasoline price again much below other commodities and below its own 1913 average.

The new price cycle, which we are at present experiencing, began actually on December 14th with the rise of Pennsylvania crude oil to $2·85 and thence by quick steps to $4·50 per barrel. This was a rise of 73 per cent. in a few months, the steepness of which may be appreciated from the fact that before the war the average annual rise during the upward phase of a price cycle for all commodities was no more than 4 per cent. In January this year the crude oil index number went up 34 points and that for gasoline 13 points. This upward movement is now stationary. In gasoline it has experienced some reaction which must be attributed in quite a considerable measure to the severe and longdrawn winter. And this brings out another incalculable factor in the oil business which is applicable especially to gasoline. The consumption of gasoline in the United States is approximately twenty times our consumption in this country. We know well what effect a fine Easter has on the consumption of petrol here. A similar number of fine days in America has twenty times the effect, and consequently a fine week spread over a considerable area of the United States may easily make a difference of 100,000 tons in the consumption of motor spirit, and a winter carrying on through most of the spring, as it has this year, naturally has a very large effect upon the total available supplies. However, this factor applies only to gasoline. The rather high prices for crude oil are tempting out the wild-catter and are increasing drilling operations, and on the success of these depends the date when production will increase. If it should coincide with the autumn, when demand slackens, then we should see probably the wave moving in a downward direction. If, on the other hand, it coincides with the spring we may see insufficient supplies in the winter and an inhibition of the seasonal absorption of stocks in the spring following.

This brief analysis of oil price cycles will have shown in the first place that the law of supply and demand governs oil prices as all others; in the second place that the oscillations in the prices of crude oil are much more extreme than those in the prices of petrol and of all commodities averaged, and that, moreover, petrol prices show a much smaller departure from the 1913 level than "other commodities." What are the causes of these peculiarities? Fundamentally, the extremities of crude oil prices are due to the unique conditions of chance and competition under which the oil production business is carried on. The comparatively much smaller fluctuations and much lower average of gasoline prices are a direct consequence of the functions exercised by the great organisations of the oil industry. Let us shortly consider these points in further detail.

There is, in the first place, a greater degree of pure chance in the mining of oil than of any other product. In mining for solid

minerals the ore-body can be blocked out by shafts and cross-cuts, and by assaying the samples so obtained the ore reserves can be calculated with blessed precision. And the ore will not run away in the meantime. But oil, being a liquid, is an exceptionally elusive mineral. There have been cases of wells brought in successfully and capped, which, on being opened up later on, produced nothing but salt water. The science of oil geology has made great strides forward, but as yet no man can foretell with certainty that oil will be discovered in a particular place; still less can he say what quantities will be found, and that is after all the most important point if one is estimating the economic effect of a discovery of oil. An oil geologist—perhaps the greatest in the world—once said to me: "If I knew for certain where oil could be found I should not be advising others but drilling for it myself." I do not know how many oil geologists there are in the world, but I think they are many and that very few of them, if any, are drilling for it themselves. That is a measure of the great uncertainty attending the oil business. It is not very long ago that the American papers were full of alarmist calculations about the early exhaustion of their oil supplies, but the discovery of the Signal Hill field in California, and of other fields since, completely turned the tide, and in 1923 the production of the United States reached the record figure of 722,000,000 barrels—53 per cent. more than the figure in 1921, which had been prophesied as the peak of American oil production. In 1923, no doubt, chance had more than her usual run in the oilfields. It has been pointed out that while in the course of sixty-four years only sixteen oilfields in the United States have ever attained a rate of production in excess of 100,000 barrels daily, yet of these sixteen fields no less than eight reached their maximum output within a period of seven months in 1923. It may be years before such an extraordinary phenomenon occurs again, but it illustrates the unusual degree of chance to which the oil production business is continually subjected. If it had not been for the distance of the Californian field we should no doubt all have felt the effects more severely. Often chance makes sport the other way, and calls up salt water instead of oil. One night in November, 1919, a certain Mexican well showed signs of salt water emulsion. This had been the world's biggest well, and its collapse marked the beginning of the serious drop in the production of the prolific Southern fields of Mexico. In January, 1922, those fields were producing daily 544,277 barrels; in January, 1923, 227,730 barrels a day; in December, 1923, they were producing only 117,250 barrels a day, a total decline of 77 per cent. Or take the case of the Powell field in Texas. The first commercial producer in this field was completed in January, 1923, but active development did not start till late in May. In June about 10,000

barrels a day were being produced. In less than five months there was an increase in output of 3360 per cent. Then in less than two months there was a decline of about 75 per cent. from the peak of 346,000 barrels a day. Such is the element of chance inherent in the business of oil production.

Drilling, it must not be forgotten, is necessarily carried on many months ahead of production, and is frequently dictated by considerations which have no relation to the market. I have already drawn attention to the elusive consequence of the fact that our product is a liquid. If the oil is discovered in a place in which there are many owners, anyone can set the pace at which the whole field must bore, and seeing that the man who gets down first and secures the first flush production probably does infinitely better than those who follow, there is in every such case an almost immediate race down to get the oil, with the consequence that the field is rapidly exhausted. This not only greatly aggravates the extent of the price fluctuations, but gives rise to an immense waste of capital, which must ultimately increase the cost of the product. No better illustration of the folly of unrestricted competition in a field could be given than the scene of the Los Angeles (California) and Powell (Texas) oilfields last year. One of the worst gluts known in the Californian oil markets in no wise curbed the feverish drilling of small operators, who crammed five or six wells on acre plots, while the competition between big groups in the Powell field rushed up the daily production of that field to 346,000 barrels and completed the general havoc. Just as production cannot quickly be scaled down to meet a decrease in consumption, so it cannot quickly be speeded up to meet an increase. I have mentioned that drilling is many months ahead of production, and that results are never capable of precise estimate. To enlarge the rate of the world's output requires time. Not only must drilling schedules be extended, but wild-cat operations on a big scale must be undertaken. Small producers either have not the available funds to carry on a greatly increased programme of drilling, or refuse to take the risks incidental thereto except it be under the temptation of rapidly rising prices. Now the world's production of oil still depends largely on these small producers. The production of the Royal Dutch-Shell Group is at the rate of about 100,000,000 barrels per annum; that of the Standard Oil Companies combined may be taken at about 150,000,000 barrels; and that of the Anglo-Persian-Burmah Group at about 35,000,000 barrels. The total of these three—285,000,000 barrels—still leaves about 715,000,000 barrels, or roughly 71 per cent. of the world's production, to be accounted for by producers independent of any great organisation. That is why, on the one hand, the

wave of crude oil prices must sometimes rise to dizzy heights before the extra drilling and wild-catting are undertaken and the extra output can be won ; or why, on the other hand, it must sometimes sink to abysmal depths before competition in the field among the small companies is checked. The great organisations have nothing to do with either rise or fall. In fact, it is because they can eliminate neither chance nor competition in the oil production business that crude oil prices are subject to these violent oscillations.

Let us now consider why in the petrol price cycles the amplitude of the waves is smaller, the ups and downs less steep, although the cycles are in general consonance with the trend of crude oil. Here it will be found that the great organisations apply an effective brake. While they cannot reduce the amplitude of the curve of crude oil prices, they can in a measure protect the consumer from the full force of the waves. The figures which I have quoted indicate that in every case the index number of gasoline was below that of the average of all commodities. There are sound economic reasons why the great organisations can and do effect stabilisation in gasoline prices at a lower level than would be possible for individual single-unit companies, why, in other words, they can afford to charge a lower price and take a smaller ratio of profit. Let us consider how this comes about.

Obviously, the organisation which embraces all the correlated functions of production, transport, refining and marketing is the most efficient organisation for the oil business. It is also the safest, that is, from the point of view of eliminating risks, and risks are among the most expensive things in business. It minimises the financial risks attached to each functional activity if it were carried on independently of the rest. A single producer of the crude oil is at the mercy of the oil refiner when there is a surplus of the raw material. A single refiner is at the mercy of the producer when there is a shortage of the raw material. The mere merchant is at the mercy of both at all times : indeed, few merchants can ride the waves of the oil price cycles and live. The violent price storms of the oil industry can only be safely weathered by the great organisations. That is why—by the law of survival of the fittest—they largely dominate the marketing of oil products.

How does this benefit the oil consumer ?

In the first place, they can ensure continuity of supply and economy in distribution. An oilfield, it must be remembered, is a wasting asset and so-called profits often represent a mere return of used-up capital. A prudent company must be continually seeking to reinvest this capital so as to secure new reserve sources of supply. It is financially unsound, if not impossible, for a single-unit producer to attempt to acquire and develop reserve oilfields out of the surplus

earnings derived from one oilfield. Only the organisations with surplus earnings derived from many oilfields and with large capital resources can afford to undertake the risks incidental to the acquisition of reserve fields, perhaps in remote corners of the globe, where the expenses of colonisation, of providing means of transport, of educating labour and so on, are part and parcel of the expenditure on drilling.

Economy in distribution follows from a world-wide distribution of sources of production. The distribution of oil to the world's markets cannot, in fact, be economically handled unless the world itself be regarded as a pipe-line. Any particular market must be fed from the nearest section of the world pipe. It is not generally an economic proceeding, for example, to ship oil half round the world to a refinery in one consuming centre and then reship the refined products, surplus to that market, to other consuming centres. Apart from the additional transportation costs, the oil is handled four times instead of twice. But with refineries situated at or near sources of production widely distributed round the world, the great organisation can ship refined products direct to the nearest points of consumption and let the surplus flow on to the next nearest point at the minimum of expense. If there be a surplus in one part of the world it can move the surplus to another where there is a deficiency, but those are the only conditions under which it allows its oil to take long journeys and accumulate transportation costs.

Another factor which makes for some stabilisation is in the holding of large stocks. This involves large locking up of financial resources, not only in the products themselves, but in the special storage installations in which alone oil can be stored. It will be understood by everyone that both the willingness to accumulate large stocks of oil and the willingness to draw on them when supplies are short are strong stabilising forces. In this connection the great organisations act towards the small producer very much as a banker acts towards traders in need of credit when there is delay in turning over their goods. They can take and store the oil which may come out in an unexpected gusher and which the small producer cannot handle. A very interesting instance of this occurred recently in Trinidad, when for a short time a very large unexpected production arose which the actual producer would have been quite unable to handle, but which a great organisation was able to handle by diverting steamers to load in Trinidad, where there was no spare storage, and allowing stocks to accumulate in Mexico, where it possessed very large quantities of spare storage. Just so does a banker lend credit to a trader who cannot sell or move his goods in time of trade depression. On the other hand, if over-production is rampant, even the pipe-lines and the tanks and the ships of the great

organisation may not enable it to take all the oil which the small producer has available: in fact there are limits in this operation, just as, in periods of inflation, the banker cannot grant to an unlimited extent the credits which traders may desire. This too has its effect in stabilising prices at the other end of the scale.

The fact that this power is used to stabilise prices has been curiously illustrated by the history of the oil market in this country. Attracted from time to time by articles which have appeared in the newspapers suggesting that exorbitant prices are being obtained for petroleum products in this country, American refiners, one after another, have sent representatives over here with a view to studying the market and taking advantage of these attractive prices. The result of that study has been that they decide not to establish themselves here because detailed study revealed to them that over any reasonable period the average price at which petroleum products are sold here by the great distributing organisations is not sufficient to cover the cost of oil in the free markets of America and of shipping and distributing to the consumer. The fact is that the great organisations can only maintain their immensely costly services of distribution to almost every street in the towns and almost every village throughout the country if they continue to do practically the whole trade, and in order that they may continue to do this they are compelled by the most inexorable economic considerations to maintain their prices at such a level that it pays no one seriously to compete with them. But, as I have said before, all this stabilisation can only be carried out even by the great organisations within very narrow limits. If, for instance, crude oil prices soar upwards and remain there for very long periods, gasoline prices cannot be kept down unless some other product goes up in price to a sufficient extent to pay for the deficiency. Actually, owing to the very small proportion of gasoline in some of the crude oils, which are the main sources of fuel oil, the curves of prices show that fuel oil moves much more closely with the crude oil fluctuations than does gasoline.

There is, however, a constant tendency for the price divergences in the different oil products to diminish as the progress of knowledge enables us more and more to convert one into the other. To-day there are processes by which fuel oil can be converted into petrol. They are at present costly and wasteful, and they can, therefore, only be carried on so long as there is a large difference in value between the two products; but the processes are being constantly improved and it is not at all difficult to imagine a time when fuel oil may become much more valuable than petrol, because whereas petrol cannot be converted into any other oil product, fuel oil seems likely to a growing extent to be available either for use as such or

for conversion into petrol and also, quite possibly, into various other petroleum products.

Separately considered, then, the oscillations in the price of one oil product may be quite different from those of another, being subject to different influences; but if the index numbers of the weighted average of the prices of gasoline, kerosene, fuel oil, Diesel oil and lubricating oil be taken, it will be found that they are much less violent than those of the crude oil from which they are produced and much more in consonance with those of other commodities. It is, of course, characteristic of all industries that the first to suffer collapse in times of depression and the first to enjoy prosperity in times of boom is the producer of the raw material, but in the oil industry this fortunate general tendency which protects the consumer from the most violent fluctuations is further strengthened by the great oil organisations, who thus not only make for whatever degree of stabilisation is possible in crude prices but also assist in minimising their effect upon the prices of products.

Finally, I should like to draw attention to the not irrelevant fact that the great organisations fill perhaps one of the most important functions in the economic world—the function of research. It is a function which small companies cannot afford. An American economist has written: "A great many people are coming to believe that it is safer and better to judge the future of a corporation or of an industry by its fixed attitude towards research than by its working capital, its past earning power or its fixed assets." This may be an exaggeration, but it certainly contains a germ of truth.

The great organisation with which I am most familiar has for many years pursued a very active policy of scientific research. It has not always been easy to place the results in the hands of the public, but one perhaps rather notable result has been the revolution in our conception of what are the valuable properties in motor fuel. I remember the day when specific gravity was supreme. Later we got as far as observing the effect of putting the stuff into a flask and boiling it. To-day we know that neither of these observations is of much help towards determining the value of motor spirit, and that until you know the chemical constitution of a motor fuel you cannot say what its value will be in the engine. But it is interesting to notice that the spirit which ten years ago was sold as No. 3 in this country was found to be the best spirit which had ever so far been produced for running an aeroplane or a motor car, and when, as a result of this exact knowledge, it was decided to call this our No. 1 spirit, we found that the demand for No. 1 spirit, which had previously been, I think, only 40 per cent. of the total demand, rapidly increased to 60 per cent., and is I believe still to-day increasing.

That is only one result of research which has had the most far-reaching economic consequences ; but apart from such big results there are of course innumerable small improvements in the processes of refining and blending and distilling which are taking place every day, all of which tend to provide the consumer with better and cheaper products.

If one were to sum up the reasons why the equilibrium between supply and demand in the oil industry is presently impossible to maintain, why the oscillations in the prices of crude oil are more violent than those of other raw materials, one might say that the oil industry has not yet attained maturity. It is only sixty years old ; it is still practically in its infancy. Although crude oil prices fluctuate widely, yet each year much more oil is produced and consumed than in the year before. Over the period from 1890 to 1920 supplies have increased, broadly speaking, by about 10 per cent. per annum. It is not impossible that eventually production and consumption will settle down to more steady conditions. There may come a time when the uses for oil cannot be much further developed and when the flush production of oil has died away. Long settled production from the world's great oilfields is not an impossible conception. The settled production of the old Appalachian field in the United States, for example, is one of the most remarkable features in oil history. Its output to-day is not much below its output in 1890. I know of no field in the world which has become completely exhausted. If ever an era of settled production is reached and stability achieved, then oil price cycles will be less violent, but costs will be very high and the stabilisation will, I think, be at a far higher level than anything of which we have to-day any conception.

There are those who talk of the ultimate exhaustion of the coal and oil supplies of the world, and ask what we are then to do for power. Sometimes those who are trying to look far ahead suggest that there should be greater conservation. Personally I have little sympathy with these peerings into the far future. Each generation must after all largely take care of itself, and if one reflects that anyone trying to estimate the future sources of power in the world sixty years ago would have left oil entirely out of his calculations, that is enough to make one realise the futility of cramping development in our generation in the hope that we may benefit a future one. For instance, we know already that there are large intra-atomic forces that are inherent in the properties of matter but which have not yet been tapped, and who knows in the far distant future these may not provide a far greater source of power than those on which we are now depending ?

I hope I have shown that at any rate in this generation the great oil organisations are playing their part and serving not only the

industry but also the whole community in no small measure. I always remember the Minister who, having been advised by his Department to make a conciliatory and true public statement to the effect that he always found the great oil concerns ready to serve the State, looked up at his audience when he was actually making his speech and was tempted to add the words, "at a price." The Minister, I think, reflected for a moment the prejudices of his audience: the permanent officials had based themselves on cold, solid, ascertained facts. If anyone cares to study the accounts of the great oil concerns, I think he will agree that the price of the remarkable service they render is an extremely moderate one. Looking only at the organisation of which I have more detailed knowledge, I find that its profits from all sources accumulated together and expressed in terms of its production represent an average annual profit of about three-farthings per gallon. That is throwing in profits on purchased oil, profits on colossal fleets, interest on all the capital invested in tank installations, in lands held throughout every country and in the great and costly distributing organisations which have been developed in every consuming country. I think this figure may be held to justify the contention that the great organisations, if they have done their work efficiently and well, if they have enabled the oil industry to develop into a highly specialised servant of mankind at a speed that has out-distanced any other trade in the history of the world, they have done so at a price which is remarkably cheap to the consumer and at the same time sufficiently profitable to investors to induce them to continue to furnish the capital funds necessary to the future of the industry in the great numbers and in the large measure which alone can enable us adequately to fulfil the needs of the age in which we live.

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INDEX NUMBERS OF THE PRICES OF

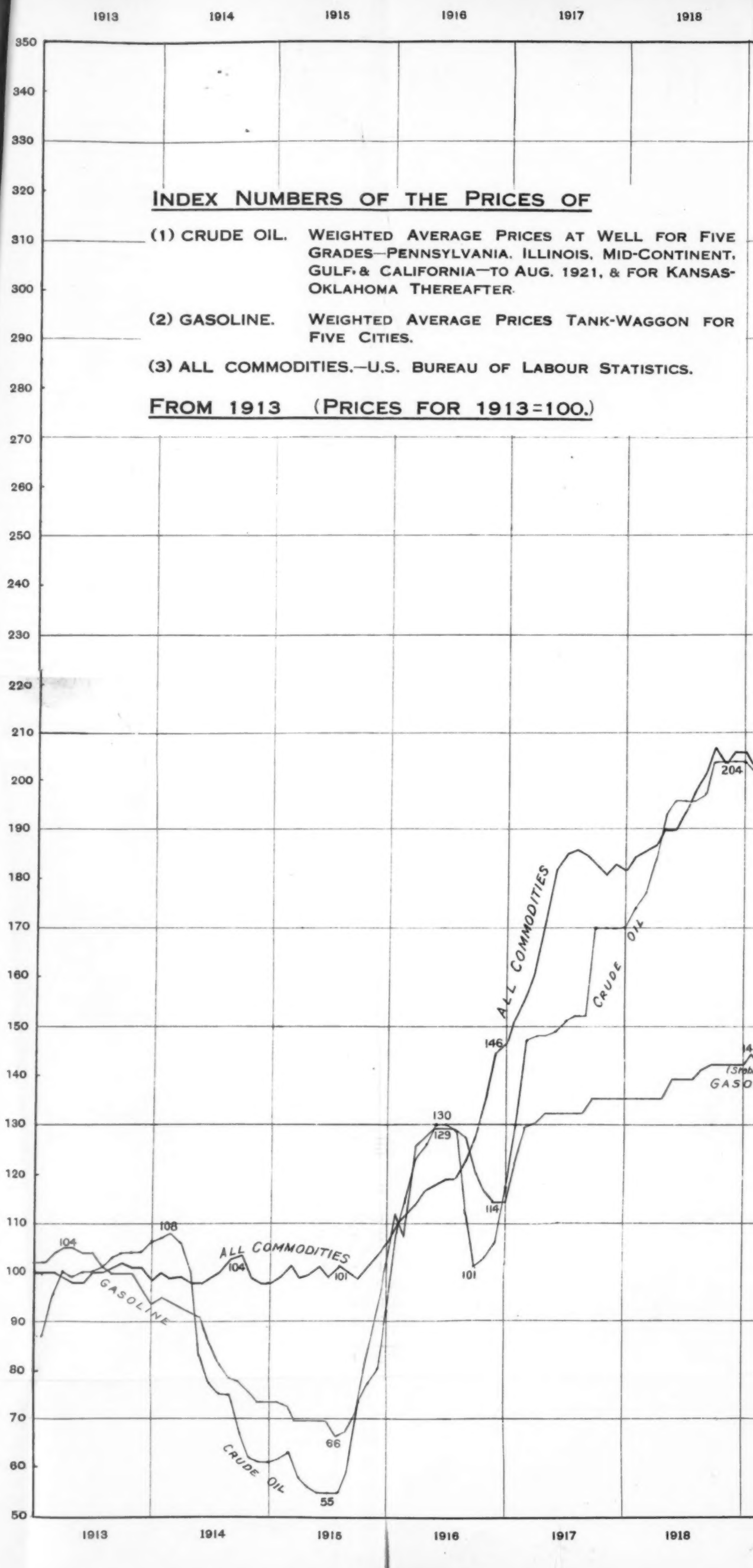
(1) CRUDE OIL. WEIGHTED AVERAGE PRICES AT WELL FOR FIVE GRADES—PENNSYLVANIA, ILLINOIS, MID-CONTINENT, GULF, & CALIFORNIA—TO AUG. 1921, & FOR KANSAS-OKLAHOMA THEREAFTER.

(2) GASOLINE. WEIGHTED AVERAGE PRICES TANK-WAGGON FOR FIVE CITIES.

(3) ALL COMMODITIES.—U.S. BUREAU OF LABOUR STATISTICS.

FROM 1913 (PRICES FOR 1913=100.)

PRICE INDEX NUMBERS. (AVERAGE FOR 1913=100.)



1919 1920 1921 1922 1923 1924

350 340 330 320 310 300 290 280 270 260 250 240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50

PRICE INDEX NUMBERS. (AVERAGE FOR 1913=100.)

314
CRUDE OIL
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1919 1920 1921 1922 1923 1924

DISCUSSION.

The Chairman said the author had stated at the commencement his paper that he was not an economist, but after hearing such a luable and interesting paper and noting the masterly way in hich the figures were dealt with, he did not think those present uld agree with the author on that point. The author had shown ry clearly how prices were controlled. When the price of petrol ent up everybody grumbled, but it really appeared to be a blessing in disguise, because the large oil-distributing companies cted as a buffer between the violent fluctuations in the prices of the crude oils and the prices of the products from them which were required by the public. There was hardly a page of the paper which would not repay very close study, and speaking personally the paper had opened his eyes to a very great extent. He thought everybody was very much indebted to the author for a paper containing so much valuable information.

Dr. A. E. Dunstan, in opening the discussion, said he desired to take the opportunity, on behalf of the Council and members of the Institution of Petroleum Technologists, of thanking the author for an extremely impressive paper. Many present occupied the position of very unimportant cogs in the great petroleum industry, viewing that industry in a very imperfect way and being very much obsessed with the details which constituted their everyday life. But the paper lifted them out of the rut; they were able to see the forest and not the trees and to get a comprehensive birdseye vision of the great forces that existed in the economic world. It was very presumptuous on his (Dr. Dunstan's) part to discuss the paper from an economic point of view, although he associated himself with the President's remark that the author must be regarded as a most able economist. The feature of the paper which appealed to him most of all as a chemist was the author's reference to the activities of the great oil associations in connection with research. It was almost a truism to say at the present time that the extent of civilisation could be measured by the consumption of sulphuric acid. In a similar way the activity of a great organisation could be measured by the extent of its investigation work. A few illustrations of that came to his mind. There was, for example, the work done by the General Electric rporation in America. Among the men in the employ of that mpany were investigators of the calibre of Langmuir, whose entific work had revolutionised the views held on atomic physics,

and incidentally had thrown great light on the phenomena of lubrication. Then there was the great Eastman organisation, which, in the course of the war, turned its activities towards the manufacture of fine chemicals, the supply of which had been cut off from America. In the author's own organisation valuable work was done by Ricardo in the elucidation of the chemistry and physics of the internal-combustion engine. Quite recently, General Motors, of Detroit, had published the results of Midgley's long investigation on the ante-detonating properties of lead tetra ethyl. All those examples illustrated the author's contention that it was the great organisations which had the capacity, the means, the ability and the tenacity to carry out great schemes of research. The smaller concerns could not possibly tackle the problems. Not so many years ago research in industry was merely a hunt after trade secrets and small details in process which were jealously guarded. At the present time the great organisations set the pace to the Universities. The insistence upon the importance of research in industry was, to his mind, one of the most valuable features of the paper, for which he desired to express his personal appreciation to the author.

Mr. Alfred W. Nash said that whilst he agreed with the author's remarks as a whole, there was one statement with which he could not agree, in that made by the author to the effect that the Maikop field proved to be of no value. This was, in his opinion, not quite correct in that Maikop never had a fair chance of being proved.

With the author's statement that the experience gained had, no doubt, been of value to those engaged in the experiment he was quite in agreement.

The system of granting small leases to anybody and everybody resulted in a number of small oil companies being formed, often with a string of even smaller subsidiary companies in their wake.

These companies were invariably poor in working capital, both in fact and in comparison with their issued capital, and were usually poorer in the technical and scientific skill at their command.

As soon as the leases were granted a wild rush was made to get down to oil, and then came disappointment: the discovery was made that the oil, being a migratory and elusive fluid, was not where the geologists hoped it would be

There followed a period of serious prospecting carried out by the richer and more powerful companies, whilst the smaller companies "sat on the fence."

If the smaller companies were content to remain on the fence for all time it would not be so bad; but as soon as oil was discovered in another area a further mad rush to get down to oil first ensued,

with the result that the bigger oil companies were compelled to put down a number of wells without any regard to scientific spacing, which resulted in that deplorable system known as "offset" drilling.

Oil sands, which may have given but a poor yield to one operator but may have been, nevertheless, very valuable elsewhere, were drilled through without any protection from upper and lower waters, with the result that those sands were often flooded before exploitation had really commenced: in addition, the whole area was considerably over-drilled in no time and the local market often ruined.

Many operators, through their own carelessness in not protecting what they considered to be someone else's sand, succeeded in flooding their own by this very means.

Such was the lesson learned by those engaged on the Maikop field, and owing to the heavy and unnecessary drilling expenses incurred insufficient working capital was left, even to the bigger companies, to enable the pay streak to be traced to its source.

He thought, nevertheless, that oil in paying quantities existed and did still exist to the N.W. or N.N.W. of the present field.

From his previous remarks it would be gathered that he was not in favour of small oil companies undertaking development work on small leases.

Rather would he prefer to see either the whole concession given over to one big company, or else see it divided into a small number of large leases to be worked by companies having sufficient working capital to treat the proposition as an industrial undertaking and not a stock exchange speculation.

Another point which had a bearing more or less on the subject of the paper was the undesirability of treating geological research as secret and confidential.

Where a number of companies were working together he would prefer to see a common geological staff working in the interests of all, but possibly there were commercial reasons why that could not be done.

The next best thing was a free exchange of information between the geological departments of all the companies concerned.

Cases were on record where good geologists had given of their best in the protection of oil sands from water, yet the field had been flooded through no fault of any individual geologist.

Had the geological information obtained by each company been looked upon as part of the whole problem instead of the whole problem in itself, a method of water extrusion could have been evolved which would have protected the whole field as well as any particular area.

It might be said that the foregoing statement had little to do with the economics of the industry, but everyone would agree that

this depended as much on the technical branch of the industry as on the science of commercial management.

Every ton of oil which was left below ground had just as bad an effect on the industry as every ton of oil which was unloaded on an already swamped market.

Another statement which was often circulated in the paper was that Well No. so-and-so had come into production and that it was under control ; whereas very often the control only applied to the direction of the flow and not to the production itself.

To allow a well to blow its maximum yield with the consequent waste of gas was just as bad as a workman giving of his maximum strength for the first hour of his shift : the ultimate yield was not nearly so great as would be the case if the flow were controlled and the wasted gas made to do useful work.

This feverish desire to get oil to the surface in large quantities in as short a space of time as possible caused just as much harm to the industry as the other evil practices to which he had referred.

Sir Robert Waley-Cohen, in reply, said the remarks made by Mr. Nash on the subject of Maikop illustrated the point made in the paper that much could be learned from the expensive experiment at Maikop. He thought it had been shown much more clearly than he had done in the paper that there was an economic experiment at Maikop which proved a failure. Although people were not always ready to learn from other people's experience, he thought if the world in general would learn by the experience of Maikop that the division of a field into a number of units rather than its development as a single unit had proved a failure at an enormous cost, that would almost justify the £8,000,000 which had been spent upon Maikop. He thought great progress had been made in the direction of the pooling of geological information. It must be remembered, however, that geologists did not always find themselves able to take the same view of a particular field. One geologist might think that certain steps were necessary and another think that such steps were foolish and that quite different steps were necessary. When people were seriously working together in a field at the present time there was a tendency (and it certainly was the policy of the great organisations) for the geologists to meet together and exchange such information as they possessed.

He thought he had dealt with the few points raised in the course of the discussion, and it only remained for him to say that he very much appreciated the reception which the paper had been given.

On the motion of the Chairman, a very hearty vote of thanks was accorded to the author.

Petroleum Geology.

By T. Dewhurst, A.R.C.Sc., F.G.S., Member of Council of the Institution of Petroleum Technologists.

Petroleum has an extensive geographical distribution. Large and valuable oilfields occur in the United States, Mexico, Russia, the Dutch East Indies, Persia, Rumania, India, Poland, Peru, Japan, Trinidad, Venezuela, British Borneo, Egypt and Argentina. Smaller oilfields occur in Columbia, Canada, Germany, France and Italy. In addition, indications of oil occur in many other countries. For example, V. R. Garfias, in his recent work on "The Petroleum Resources of the World," deals with the prospective oilfields of over fifty additional countries, situated in all parts of the world.

Petroleum occurs in the rocks of every geological system from the Cambrian to the Pleistocene. The most important oilfields have been found in formations of the Ordovician, Silurian, Devonian, Carboniferous, Cretaceous and Tertiary systems.

Production from the Palæozoic systems is practically confined to the United States and Canada. A little production is obtained in China from Carboniferous rocks, and a little production has been obtained in England from rocks of the same age.

It is believed that the Tertiary systems yield over 50 per cent. of the world's production of oil. The main Tertiary oilfields occur along two enormous belts: (1) the Circumpacific belt, and (2) the belt formed by the large Eurasian Arc which passes through the Dutch East Indies, Burma, Assam, N.W. India, Persia, and the countries bordering the Mediterranean.

The following table, showing the distribution of the petroleum of the various geological systems, is unavoidably tentative and incomplete:—

Pleistocene.	California, Venezuela, Texas, Louisiana, Trinidad.
Pliocene.	California, Borneo, Sumatra, Italy, Croatia, Rumania.
Miocene.	California, Burma, Borneo, Sumatra, Java, Rumania, Galicia, Russia, Persia, Egypt, Japan, Trinidad, Assam, Mesopotamia, Italy, Sicily, New Zealand, Formosa, Croatia, The Philippines, Peru, Barbadoes, Algeria.
Oligocene.	California, Columbia, Trinidad, Galicia, Roumania, Russia, France, Mesopotamia, Burma, Assam.

EOCENE.	California, Venezuela, Mexico, Peru, Ecuador, Trinidad, Columbia, Galicia, Roumania, Albania, Italy, Armenia, The Punjab, Burma, Baluchistan, Madagascar, Ferghana ?
CRETACEOUS.	California, Wyoming, Louisiana, Montana, Colorado, Arkansas, Oklahoma, Western Canada, Mexico, Galicia, Sicily, Ferghana, Argentina, Egypt, Armenia, Columbia, Venezuela, Germany, Cyprus.
JURASSIC.	Wyoming, Alaska, Germany, Albania, Madagascar.
TRIASSIC.	Wyoming, Germany, Spain, France.
PERMIAN.	Montana, Wyoming, Texas, Oklahoma.
CARBONIFEROUS.	Montana, Wyoming, Texas, Arkansas, Oklahoma, Kansas, Kentucky, Illinois, Indiana, Ohio, West Virginia, Pennsylvania, China, England.
DEVONIAN.	Kentucky, Indiana, New York, Ontario.
SILURIAN.	Kentucky, Ohio, New York, Ontario.
ORDOVICIAN.	Kentucky, Illinois, Indiana, Ohio, New York, Ontario, Newfoundland.
CAMBRIAN.	New York, Ontario, Quebec.

It follows from the above table that the mother substance or substances from which petroleum was formed must have existed throughout that portion of geological time during which the fossiliferous sedimentary strata were formed, and must also have been well distributed geographically. The conditions favourable for the formation of oil must have existed in many parts of the world and have recurred frequently during geological time. We have therefore to recognise at the outset that we are not dealing with a rare and strange product which is the result of a peculiar and even unique combination of circumstances, but with a very common and abundant product which must have been formed under quite ordinary conditions.

All important accumulations of petroleum occur in sedimentary rocks. In addition, practically all seepages and surface indications of petroleum also occur in sedimentary rocks. The term "Oil Measures" is analogous, lithologically but not stratigraphically, to the well-known term "Coal Measures," and is applied to a series of strata, some of which contain petroleum. Oil Measures usually consist of shales and sandstones, or of shales and limestones. Argillaceous rocks seem to be much more abundant than the sandstones and limestones. The rocks are often very impure, sandy shales, argillaceous and calcareous sandstones, marls, and impure limestones being of common occurrence. The conditions under which the sediments were deposited apparently did not permit of very effective sorting. Oil Measures are also usually somewhat ill-consolidated.

In most oil-producing regions the petroleum is confined within definite stratigraphical limits, the Oil Measures being underlain and overlain by formations which are barren of petroleum. In

some countries the oil also occurs in sand lenses or lenticles within the Oil Measures. This evidence indicates that the petroleum is indigenous to the rocks in which it occurs, in which case it has obviously been formed from the organic remains which were deposited along with the sediments which formed the Oil Measures.

A few brief references will now be made to the nature of the Oil Measures, and to the occurrence of petroleum, in a few oil-bearing countries.

In the Punjab the principal members of the Nummulitic Series are the Lower Nummulitic Hill limestone and the overlying Upper Nummulitic Chharat groups. The Chharat beds consist mainly of red and green shales, with gypsum. Earth movement occurred after the deposition of the Hill Limestone. The petroleum was formed in the lowest beds of the Lower Chharat group.

The Dunghan Limestone of North-East Baluchistan is probably the southern representative of the Hill Nummulitic limestone of the Punjab. The Dunghan limestone is succeeded unconformably by the Ghazij shale group, which is several thousands of feet thick. It is probable that the petroleum was formed in the lowest beds of the Ghazij shale group.

In Persia the oil occurs in the Asmari limestone. Earth movement took place after the deposition of this limestone, and the Miocene Fars series was deposited unconformably on the Asmari formation. The Lower Fars group consists mainly of shales with abundant gypsum and some beds of rock salt. Petroleum occurs in the Lower Fars beds as well as in the Asmari limestone. The petroleum was probably formed in the lowest beds of the Lower Fars group.

It is believed that the remarks made in regard to Persia apply also to Mesopotamia. However, there appears to be very little evidence of unconformability between the Asmari and Fars groups of the latter country.

In Mexico the oil occurs in the Lower Cretaceous Tamasopa limestone and in the overlying Upper Cretaceous San Felipe limestones and shales. These oil-bearing strata are unconformably overlain by about 3000 ft. of Cretaceous-Eocene shales.

In the States of Ohio and Indiana gas and oil occur in considerable quantities in the upper part of the Middle Ordovician Trenton limestone, which is overlain by some hundreds of feet of shale, the well-known Utica shale. The author is unaware of the existence of any evidence of unconformability between the Trenton and Utica formations.

The above-mentioned examples of the occurrence of petroleum are submitted at the present stage merely to show that in some countries the oil occurs in the upper layers of a limestone formation which is overlain by a shale group. In some cases the shale was

deposited unconformably on the limestone, and the oil was formed in the lowest beds of the shale formation.

In the San Joaquin Valley of California the oil occurs principally in the basal members of the thick Fernando formation. The lower part of the Fernando includes the horizon of the McKittrick and underlying Santa Margarita formations of Upper Miocene age, from which great quantities of oil are obtained. The Fernando formation consists of conglomerates, sands, shales and clays.

The Fernando formation, the basal members of which contain so much oil, rests unconformably on a thick shale formation, the Monterey shale, a diatomaceous shale which is sometimes 7000 ft. thick.

In the Kern River field, which is situated on a vorland, about 5000 ft. of Tertiary rocks rest on the granite of the Sierra Nevada, which is continuous round the south end of the San Joaquin Valley. The Tertiary formations include an upper and a lower division. The upper division consists of coarse unconsolidated sands and gravels, and the lower division is composed mainly of clays and soft diatomaceous shales which represent the Monterey shale series. The lower division is regarded by Californian geologists as the source of the oil, and the upper as the main zone of accumulation.

In the McKittrick field the stratigraphy resembles that above described. The oil is believed to have originated in the diatomaceous shales of the Monterey and Santa Margarita formations, and to have migrated to the sands and gravels of the overlying McKittrick formation.

In the Sunset-Midway field the wells derive their oil from Miocene or Pliocene sandy beds, which rest unconformably upon almost 5000 ft. of diatomaceous shale.

Day gives a generalised stratigraphical table of the succession in the Maracaibo basin of Venezuela. He shows 3000 ft. of black carbonaceous shale, of Oligocene age, which is supposed by some geologists to be the original source rock of the petroleum. The thick carbonaceous shale group is succeeded by alternations of shales and sandstones, with some lignites. The sandstone beds of this upper group act as the reservoir rocks, and yield petroleum.

In Burma the oil occurs in Miocene and Oligocene beds, and also in the Upper Eocene. The Oil Measures consist largely of alternations of shale and sandstone, and they are underlain by a thick series which is very argillaceous, as it includes the Laungshe shale group, which is probably over 12,000 ft. thick, and also the Tabyin clay group, which is about 5000 ft. thick.

In Lower Assam the petroleum occurs in a thick series of alternations of shales and sandstones, and the Oil Measures are underlain by over 5000 ft. of dark grey and black shales, known as the Kayeng shale group.

A similar lithological succession has been noted in other oil-producing countries, the oil occurring in the sandstones of a thick series of alternations of shales and sandstones, with lignites, the whole resting on a thick argillaceous formation.

There has been much discussion in the past in regard to the origin of petroleum. The author does not propose to inter or to disinter any dead hypotheses, however useful they may have been in showing how oil was not formed. The only hypotheses which show any sign of animation at the present time are those which ascribe the origin of oil to changes in some form of organic matter. It has been suggested that oil has been formed from terrestrial vegetation, marine vegetation, diatoms, formanifera, fish, and other special forms of animal and plant life. It has also been suggested that coal and petroleum are complementary products of the decomposition of vegetation, and even that petroleum has resulted from the slow distillation of coals and lignites.

One cannot exaggerate the importance of the very wide geological range of petroleum in relation to its origin. It is obvious that early Palæozoic oil could not have been formed from fish remains, nor could it bear any sort of genetic relationship to coals or lignites. Similarly, there is no evidence to show that this early petroleum was formed from terrestrial vegetation. However, it does not follow that substances which are obviously inadequate if regarded as the source or sources of all known petroleum have not contributed largely to the material from which the petroleum of the younger geological systems was formed. This applies particularly to terrestrial vegetation as a source of oil. There is a close association of petroleum and lignite in many oilfields. For example, the very thick and valuable lignite seams of Upper Assam occur in the Oil Measures. The productive oilsands of the Digboi field occur just above the horizon of the main lignite seams. Rocks below the lignite seams yield numerous seepages, and may yet prove to be productive. Apart from the ignites and plant remains, the strata are barren of all megascopic fossil forms. In the absence of animal remains, the abundance of lignite and petroleum within very narrow stratigraphical limits suggests a relationship between these two substances.

Dr. Bosworth ascribed a vegetable origin to the oil of the Mid-Continent fields of the United States, as coal seams are present at intervals throughout a great part of the oil-bearing formations, and much of the clay, shale, and sandstone contains abundant carbonaceous particles derived from plants.

Lignite seams and productive oilsands occur in one and the same series in the Borneo oilfields. Lignites also occur in the Oil Measures of Venezuela. Again, lignites and petroleum are closely associated in the Oil Measures of the Arakan Coast. At Tataros, in Rumania,

adjacent beds of lignite and asphalt sand are mined together. Further, Emmons points out that many oil-producing strata are lignitic or closely associated with highly lignitic beds. There is consequently a considerable amount of evidence which suggests that the oil of a number of oilfields might very well have been formed largely from terrestrial vegetation.

However, in some oilfields there is little or no evidence to suggest that terrestrial vegetation contributed to the formation of the petroleum. This is apparently the case in the Punjab, where there is no evidence of the existence of coal or lignite in the Oil Measures. Mr. Pinfold found it so difficult to find traces of any vegetable or even animal remains which might indicate the source of the oil that he suggested its derivation from the decomposition of soft-bodied organisms, possibly seaweeds, which had left no trace of their existence. Again, the petroleum of the Persian oilfields was apparently not associated in any way with coal or lignite. The nearest coal or lignite was situated some hundreds of miles from the oilfields. It has also been pointed out that the petroleum in the early Palæozoic formations was obviously not associated with coal, lignite, or plant remains.

The absence of any constant companion or invariable associate of petroleum greatly complicates the study of the subject. A mineral may be known to some extent by its friends, but the numerous and apparently casual and even doubtful acquaintances of petroleum do not throw much light on its habits. For example, much has been written regarding the association of petroleum and rock salt. It is well known that the petroleum industry of the United States originated in the drilling of wells for brine, and the observation that gas and oil were usually found associated with it. Again, the district of Baku was formerly highly esteemed for its rock salt, and the oilfields of Rumania and Galicia include valuable salt deposits. In the Attock District of the Punjab the petroleum originated in the Lower Chharat beds, that is, in the lower portion of the Upper Nummulitic Series, while in the adjoining Kohat District there are thick deposits of rock salt of the same geological age. In Persia there are thick beds of rock salt in the Lower Fars beds, which yield copious seepages of petroleum. Thick beds of rock salt occur in the Oil Measures of Egypt, while petroleum is associated with salt plugs in Rumania, Texas and Louisiana. Some geologists even believe that Oil Measures are essentially salt measures, and that the occurrence of the oil is a secondary if not an incidental effect. It is nevertheless important to bear in mind that in some countries the oil is not associated with bedded or massive rock salt. Burma, Assam, Arakan, and the Dutch East Indies offer examples of this type of oil measures. It is true that salt water occurs in some of the porous beds. For example, the

salt "pungs" of Assam are well known and show that some salt is present in the rocks. However, it is difficult to decide if the salt is present in greater quantity than might reasonably be expected in the case of marine strata which have been so well sealed as to have retained the oil formed in them.

The above remarks regarding the association of oil and rock salt apply with greater force to the association of oil and gypsum, as the latter is often found in Oil Measures in the absence of bedded or massive rock salt. However, in some fields, such as those of Assam, there is not the least trace of the presence of gypsum.

A little sulphur is usually found in petroleum. Free sulphur is sometimes found in the neighbourhood of oil-seepages, and springs with sulphuretted hydrogen are common in outcropping oil measures.

Attention has frequently been drawn to the rich fossil faunas of oil measures. For example, the rich molluscan fauna of the oil measures of Burma has been referred to as indicating the obvious source of the oil, regardless of the fact that in the neighbouring province of Assam the Oil Measures are practically devoid of all megascopic fossil remains.

Californian geologists claim that the petroleum of that State was formed from the diatoms of the Monterey Shale. It has also been claimed that in certain countries oil has been formed in shales which have a plankton fauna. It must be admitted that evidence of the presence of these microscopic forms in oil measures is somewhat meagre, as petroleum geologists are usually too closely occupied with structure mapping and oilfield development to conduct investigations into the microscopic fauna and flora of the oil measures. This remark also applies to the analysis of oilfield waters. In this connection it is believed that the waters of the Perlak field of Northern Sumatra contain enough iodide to allow of the extraction of iodine on a commercial scale. The waters of the gas fields of Transylvania also contain a high percentage of iodide and bromide.

It would seem to be dangerous to attach too much weight to the association of petroleum with certain other substances, as most, if not all, of these substances also occur quite independently of petroleum. It is well known that coals, lignites, rock salt, gypsum, sulphur, and all kinds of fossil remains exist where there is no trace of petroleum, and certainly no great quantity of petroleum. Most petroleum geologists are also aware that these substances may be treacherous if regarded as indicators of petroleum. At the same time, they do throw some light on the conditions under which Oil Measures were deposited. Association with coals and lignites indicates that petroleum was formed close to land which supported a luxuriant vegetation. On the other

hand, association with beds of gypsum and rock salt indicates that petroleum was also formed in limited bodies of salt water, situated in arid or desert regions in which evaporation exceeded precipitation, and in which there was little, if any, vegetation.

It is convenient at this stage to consider briefly the conditions under which Oil Measures were probably deposited.

The Oil Measures of the Lake Maracaibo region were apparently deposited in an inland sea which was quite isolated from the main ocean.

The Oil Measures of the San Joaquin valley were laid down in an inland sea which was connected with the main ocean by only a narrow channel.

The Oil Measures of the Punjab were deposited in a gulf. It has been explained by Mr. Pinfold that earth movement occurred after the deposition of the Hill Limestone and cut off the waters of the upper portion of the gulf from the open sea. The oil of the Punjab was therefore formed under inland sea conditions.

In the case of Persia there was a barrier in the neighbourhood of Kalhat in Tertiary times. The sea in which the Tertiaries were deposited was either cut off entirely from the open ocean or was connected with it by only a narrow channel.

The Oil Measures of Burma were deposited in a long narrow gulf. The disposition of the formations and the abundance of gypsum in the Pegus of Central Burma suggests that the sea became partly or wholly cut off from the main ocean to allow of the concentration of the waters of the gulf.

The Oil Measures of Assam were also deposited in a gulf, and the position of the Shillong Plateau and the Mikir Hills, both of which are made up of very old rocks, suggests that the upper portion of the gulf might very well have been partly or even wholly cut off from the open sea while the Oil Measures were being deposited.

Although there may be some difficulty, owing to the present state of our knowledge, in distinguishing in some cases between original basins of deposition and basins which have been induced by earth-movement subsequent to deposition, enough has been written to direct attention to the conditions existing in inland seas and in bodies of salt water which are partly cut off from the main ocean.

Marine life is most abundant in shallow seas along the margins of continents, and above continental shelves. It is particularly abundant in the diaphanous zone and along the sea floor. When depression of a region occurs the sea invades all the low-lying lands, and there is a great expansion of the sea floor and of the

diaphanous zone. Sea expansion also favours amelioration of climate, so that such periods are likely to be periods of maximum life for the region in question.

With irregular elevation of the land and retreat of the sea large bodies of salt water might be wholly or partially separated from the open ocean. The abundant marine fauna would adjust itself to the reduction of the zones most favourable to life and to the smaller volume of water for the region in question. Such inland or semi-inland seas should be well stocked with marine life and should also provide excellent receptacles for the deposition and entombment of organic matter. The remains of animal and vegetable organisms would not be widely dispersed over the sea floor but would be caught and trapped in limited areas.

The complete or even partial separation from the main ocean not only enables enormous quantities of organic matter to be trapped and concentrated in limited areas, but other important changes probably occur. The inland seas are sheltered from disturbing ocean currents and from all oceanic circulation, and this would appear to have important consequences. Walther states that as long as a part of the sea is in open circulation with the ocean and its waters are constantly interchanged and the normal salinity maintained, there will live and be continued a normal marine fauna. As soon, however, as the free circulation of the water ceases, all normal conditions are altered. Such stagnant places are characterised by accumulations of organic matter, by the development of poisonous sulphuretted hydrogen gas in the water, and by the vanishing of bottom living organisms. Similar conclusions were given in an article in "Zeitschrift für practische Geologie," No. 9, September, 1920. Pirsson and Schuchert state that such bottom waters are stale, and are taken possession of by sulphur-making bacteria which feed on the micro-organisms and other life which falls from the sun-lit, oxygen-absorbing surface zone. As a result of the bacterial life processes, the bottom waters become more and more foul through the liberation of sulphuretted hydrogen gas. Emmons even refers to a petroleum bacillus (*Micrococcus petroli*). Spielman recently reviewed the literature dealing with the genesis of petroleum and concluded that animal and vegetable matter, accumulating rapidly at the bottom of saline or brackish seas and lagoons, was attacked by bacteria which caused the decomposition of protein matter mainly to soluble substances and gas. The fats become split by bacterial action or by hydrolysis, to form soluble glycerine and fatty acids. The presence of saline substances in the water caused an increased accumulation of fatty acids, and modifying the ordinary course of decay caused the decomposition to proceed in the direction of petroleum.

If a stagnant sea area were situated in a region favourable to the growth of luxuriant vegetation it might very well be bordered by swamps favourable to the subsequent formation of lignites and coals. It is probable that in these conditions vegetable remain would contribute largely to the oil-forming material, though it is difficult to exclude the possibility, and even the strong probability that the fauna of the diaphanous zone, and particularly th plankton, also contributed its quota to the mother substance o the petroleum.

On the other hand, if the stagnant sea area were located in an arid or desert region, where evaporation exceeded precipitation, it is probable that very few remains of terrestrial vegetation would be deposited with the sediments, and that the petroleum would be formed largely from the fauna of the diaphanous zone and particularly from the plankton.

As a result of this brief study of the geological conditions under which petroleum exists, and of the conditions most favourable to the deposition, accumulation, and decomposition in situ of large quantities of organic matter, it is suggested that petroleum in large quantities was probably formed from any and every available kind of organic matter which was deposited in stagnant sea areas, such as would ordinarily be provided by inland and semi-inland seas, lagoons, sheltered gulfs and bays, etc.

It is generally held by petroleum geologists that during the consolidation of the various sediments to form oil measures, the fluids gas, oil, and water would ultimately be squeezed into the most porous beds of the series. If the sediments remained in the horizontal position, the oil would probably occur as scattered globules throughout the coarser sediments in the central part of the area of deposition. When earth movement occurred and the rocks were tilted from the horizontal, the fluids within the basin would tend to arrange themselves according to gravity. If through folding and denudation the oil-bearing beds became exposed to the atmosphere oil would seep out at the surface. As much oil as possible would escape from the basin as folding and denudation proceeded. The student of petroleum geology should get a firm grip of this conception of the existence of oil basins from which the oil is tending to escape. From the scientific point of view the escape of oil at the surface is probably more important than is its retention in pools of commercial value. In some countries, and particularly in those where the oil measures have been much tilted and denuded, the percentage of oil which has been prevented from escaping and has been retained in the rocks is probably small compared with the quantity which has escaped.

It is obvious that the accumulations of oil which are likely to prove of commercial value will occur only in those portions of

the basin to which oil has migrated in considerable quantities, and where escape has been prevented. As is well known, escape is usually prevented by the existence of domes, anticlines, terraces, spurs, changes of strike, lenticular sands, faults, sealing at outcrop, etc.

Favourable geological structures such as domes, anticlines, terraces, etc., have acquired very great importance in petroleum geology because of their capacity for retaining petroleum in commercial quantities. The author is almost tempted to suggest that this aspect of favourable geological structure has received undue attention, and is perhaps even a secondary matter. Oil occurs in commercial quantities in an area not only because the geological structure is favourable for the retention of oil, but primarily because oil has migrated into the structure in commercial quantities. For example, Emmons states that there are over one hundred anticlines and domes in the State of Wyoming. Many of these have been drilled without yielding oil or gas. About a score have proved to be productive, and more than half of these have produced oil in considerable quantities.

It is important to bear in mind that there may be many domes and other favourable structures in an oil-producing country, and that in all these structures known oil-bearing horizons may lie within reach of the drill, so that at first sight all may appear to offer equal prospects of becoming valuable oilfields. However, despite the closest apparent similarity of the areas in regard to structure and geological horizon, it is extremely probable that only a few of the structures will contain oil in paying quantities, and that the rest will be practically barren of oil. The distinction between the structures which are likely to contain oil in paying quantities, and those which are likely to be barren, presents the most important practical problem with which petroleum geologists are ordinarily confronted.

One of the most interesting examples bearing on this problem is provided by the Big Horn Basin in Wyoming. This basin is a depression nearly surrounded by high mountain ranges, the Big Horn Mountains, the Owl Creek and Bridger Ranges, and the Shoshone Mountains. The rocks dip from the mountains towards the centre of the basin, where the older formations are deeply buried. The basin may be separated into two parts, an inner or central part, in which the Upper Tertiary and younger beds are almost horizontal, but dip slightly towards the middle trough, and an outer or border part adjacent to the mountains, in which older beds are thrown into small folds. Near the mountains there are two almost completely circular chains of anticlines and domes, one inside the other. It is most important to note that the inner circle of anticlines and domes has yielded almost the entire production

of the area. Hewit and Lupton state that every tested field in the Big Horn Basin which has yielded appreciable quantities of oil and gas lies towards the principal trough of the basin, and every tested upfold which is separated from this trough by other folds has either yielded water and the merest traces of oil and gas or is barren. Furthermore, in the three most productive fields of the basin, the Grey Bull dome, the Torchlight dome, and the Grass Creek anticline—the last named being a very elongated dome—the oilpools extend much lower down the flat basinward flanks than on the steep mountainward limbs.

The Los Angeles basin presents evidence showing the importance of the position occupied by suitable structures with reference to drainage. To the south-east of Los Angeles there is a geosyncline, on each side of which is situated an anticline. The Santa Fe Springs dome is situated on the north-eastern anticline, while the Signal Hill or Long Beach dome, and the Huntington Beach dome, are situated on the south-western anticline. These three domes are extremely rich in oil, and rank among the biggest producing fields in existence. The extraordinary richness of these domes is evidently related to the commanding positions they occupy with reference to the large drainage area provided by the long flanks of the geosyncline.

The rich oilfields of the San Joaquin Valley of California also occur on both flanks of a geosyncline. The Kern River field is situated on a vorland on the eastern side of the geosyncline, but most of the fields occur on the western side and are situated on geological "spurs," or the pitching ends of anticlines which project obliquely into the basin.

Again, south of the Transylvanian Alps in Rumania there is a wide geosyncline, on the northern flank of which there are two belts of anticlinal structure. It is important to note that the southern belt is the richest in oil. The oil has migrated up the flank of the geosyncline and has been caught mainly in the first or nearest anticlinal belt, which provided a barrier to the further migration of the greater part of the petroleum.

The above illustrations are merely intended to draw attention to the great importance of the study of the migration of petroleum within a belt or basin. It is impossible to exaggerate the practical importance of this branch of petroleum geology.

There has possibly been a slight tendency in recent years to under-estimate the value of oil seepages. In case this surmise is correct, the author would record his opinion that seepages of oil are of the greatest importance in working out the problem of the migration and accumulation of oil within a basin or belt. The occurrence of oil at any point at the surface shows that the conditions have enabled the oil to migrate to that point, and this

small piece of evidence must be shown to be in harmony with the rest of the evidence bearing on the migration of oil within the basin.

An oil seepage indicates that oil will have migrated to the same spot, but also possibly further, in any lower and concealed oil measures that may exist, and if there is closed geological structure in the neighbourhood, oil may have accumulated in quantity in the highest parts of this favourable structure.

The author has seen a little evidence which suggests that oil seepages sometimes occur in an anticline at points which are nearest to the saddles of a neighbouring anticline. It may be that a little oil has passed over the low saddles of one anticline so as to reach the next anticline. It would seem to be this peculiar aspect of the migration of oil which has led some American petroleum geologists to refer to a saddle as the "spill over" of an anticline.

It is possible that the character of oil is affected by the extent of the migration it undergoes. For example, Rogers states that the interaction between the waters and the oil produces changes in the latter. The oxygen and sulphur formed polymerise the oil, forming heavier and more complex hydrocarbons. Consequently, the further the oil migrates and the more water it comes in contact with, the more asphaltic it becomes.

It is possible that in the early stages of the denudation of folded oil measures the oil would seep out in most places where the oil rocks cropped out, and that the seepages would be most numerous and prolific at this period. In a more mature basin or belt, in which the oil rocks have been exposed for a long period, the oil will probably have entirely escaped from those portions of the general structure to which it did not migrate in large quantities. This subject is of interest, as it may yet be shown that the degree of significance which should be attached to seepages as indications of the points to which oil has migrated in the greatest quantities is dependent on the length of time during which the oil measures have been exposed at the surface.

While dealing with the subject of the migration of petroleum, attention may be called to the importance of the size of the drainage areas of suitable geological structures. The author is unaware of the existence of a large oilfield which has not a large drainage area. In the case of one important oilfield the drainage area is about 950 square miles, while the concentration area is about 1¼ square miles. Other things being equal, the richest oilpools will occur where the concentration area is small compared with the drainage area. This subject will receive further attention when geological structures are being considered in detail.

Some petroleum geologists believe that there has been much vertical migration of petroleum. It has indeed been stated that such migration is not only usual, but inevitable, in view of the conditions under which petroleum occurs, and that there has even been a separation and a sorting of various kinds of petroleum which have ultimately arranged themselves in accordance with the rock pressures existing at various depths. The author understands that the final arrangement of the pressure-fractions according to this hypothesis is as follows, in descending order:—

(1) Methane.

(2) Lubricating oils, without paraffin, benzine or tar.

(3) Benzines.

(4) Paraffin oils.

The author is not aware that this hypothetical arrangement of various kinds of petroleum according to rock pressure holds good in any oilfield. Furthermore, it has been found that cases of supposed vertical migration of petroleum are usually susceptible of a simpler and more rational explanation.

A very interesting case of supposed vertical migration of petroleum is presented by the Khaur oilfield, situated in the Punjab. All petroleum geologists who have worked in the Punjab agree that the oil was formed in the Lower Chharat beds of the Upper Nummulitic Series, and there is abundant evidence in support of this conclusion. In spite of this fact, the oil of the Khaur field is not produced from the Chharat beds, but from the sandstones of the higher Murree Series. It has therefore been assumed that the petroleum has migrated vertically from the Lower Chharat beds, through several thousand feet of shales and sandstones, to its present positions in the Murree Series. If the degree of vertical migration involved in this hypothesis were admissible, one would be faced with the greater difficulty of explaining why the oil in most oilfields ever came to rest in its present positions and avoided further vertical migration and complete dissipation into the atmosphere. However, the problem of the accumulation of oil in the Murrees of the Khaur field is susceptible of a simple explanation which is in harmony with the known facts. The Murree Series thins and disappears to the south, and successive horizons come into contact with the Lower Chharat beds, and it is probable that the oil entered the more porous horizons of the Murrees at the points of contact with the oil measures. On entering these porous beds the oil migrated laterally until it found a resting-place in the Khaur dome.

When an oil series impinges on a plane of unconformability and overlap much oil may migrate along this plane and find its way either into a higher or a lower series. Probably the most common example of this kind of migration and accumulation is provided by the broad folding of a limestone group, with the formation of synclinal basins in which oil was formed. In the centre of these basins the oil would be formed in rocks which are conformable with the limestone. If subsidence occurred the successive deposits would overlap and even the limestone anticlines might be covered with sediment. Continuation of the folding movement would cause a synclinal disposition of the oil measures and the oil would migrate into the plane of unconformability and overlap and would finally come to rest at the summits of the limestone domes.

A little evidence has been found in one or two countries which suggests that yielding to further movement has taken place along the plane of unconformability and overlap, and that the limestone domes have been thrust into the younger beds.

Petroleum geologists spend much of their time in the detailed mapping of anticlines, and a few words may be devoted to the various types of structure which are usually met with. They range from extremely gently dipping domes to highly complex fold-faults.

The simplest type of structure is that of the gentle dome. The author has seen in some countries, and notably in South-Eastern Persia, large gentle domes which stand out topographically like gigantic tortoise shells.

Many rich oilfields occur on dome structures for the simple reason that these structures provide the smallest concentration areas for the oil, and they usually have large or fairly large drainage areas. They usually gather oil from a large area and store it in a very small area.

It is somewhat surprising to find that many gentle domes are much faulted, the faults being usually dip faults. Examples are the Yenangyoung dome and several other domes in Burma, the domes of the Big Horn Basin, etc.

The faults in gentle oilfield structures seem to have had no injurious effect on the accumulation of the oil in the domes. Earth movement must have preceded migration as cause precedes effect, but there is only a little evidence to indicate that the migration of oil was probably complete before faulting took place. In the case of one important field a prominent fault occurs beyond the known limit of the oilpools and the evidence at present available from wells suggests that oil has not accumulated beyond the fault, indicating that the migration of oil into the dome was complete before faulting took place just beyond the limits of the pools.

The Yenangyoung dome is a compound dome with one crest maximum at the south end of the Beme Reserve. A longitudinal section of the field discloses what may perhaps be referred to as a northerly hade with its apex at the Beme crest maximum. A number of dip faults converge towards the apex of this structure, the throw of the faults decreasing as the summit is approached. Mud veins are extremely numerous in this part of the field. They are dip veins, and like the faults they strike towards the apex of the structure. The mud veins are most abundant at the dome centre, where they form a close interlacing network. The distribution and orientation of the mud veins shows that they are closely connected with the apical region of the dome. The mud of the veins was derived from the clays of the oil measures. It is suggested that the veins are the dissected roots and rootlets of a former group of mud volcanoes. It is probable that following on the formation of the dome enormous quantities of gas collected at the dome summit under very great pressure and forced its way along joints and tiny crevices to the surface. As the climate was probably dry, the resulting mud volcanoes probably had cones of considerable size. It is probable that enormous volumes of gas escaped, and that when the gas pressure fell the veins were left full of liquid mud which eventually solidified. Denudation then removed the cones and disclosed the underlying roots and rootlets of the volcanoes as the mud veins of to-day. The mud veins are distinct from the faults, which are possibly of later age.

While referring to the subject of mud volcanoes it is perhaps worthy of mention that they are of very doubtful value as indications of the presence of petroleum. Although mud volcanoes occur in some rich oil-producing regions, as for example in Burma, Trinidad, and in the neighbourhood of Baku, they also occur in countries and areas where there is no oil. In a dry region a little gas may be responsible for quite impressive mud volcanoes.

Very gentle domes are sometimes very strongly faulted. The best example known to the author is the Ondwe dome in Burma. This is a large and extremely gentle dome, yet it is traversed by a large fault which has displaced the axis nearly three-quarters of a mile.

It is probable that, from a strictly accurate and theoretical point of view, all or nearly all anticlines are asymmetrical. In practice, however, all anticlines which approximate to symmetry are classed as being symmetrical. The term "asymmetrical anticline" is usually applied only to those folds in which there is an obvious and marked difference in the dip of the flanks. The shallower flank of an asymmetrical anticline is usually situated on the side of the syncline which has the greater amplitude. Anticlines

which are situated along the margin of a geosyncline usually have their gentler flanks dipping towards the axis of the geosyncline. In other words, the axes of such anticlines hade towards the geosyncline. This arrangement is probably the main cause of the very frequent occurrence of oil in commercial quantities in the gentler flanks of asymmetrical anticlines, and of its absence in paying quantities in the steeper limbs. It is, of course, not claimed that this disposition of the oil is universally true, but it is so common as to be well worthy of comment.

An asymmetrical anticline which has a long elevated core is not so favourable for high concentration of oil as is the simple isolated dome. The reason for this is that slight changes in pitch result in a very long area being favourable for the reception of the oil. In these cases the ratio between the concentration area and the drainage area is much less than is the case in isolated domes. The quantity of oil is limited, and if it collects in a very long repository the oilpools will be very narrow indeed and no one part of the area will be very rich in oil. The testing and development of such areas is a matter of some difficulty and in some cases the results are not very satisfactory. Were the oil which is dispersed in a long narrow anticline concentrated in a simple dome it would probably form a rich and valuable accumulation.

A certain amount of evidence has been obtained which indicates that the beds forming an anticline have not a uniform thickness throughout the curve of the fold. It has been noticed by several observers that beds are thinner on the steep flank than they are on the gentle flank. In the case of one asymmetrical anticline it was proved by the most careful measurements that the argillaceous beds on the steep flank were only two-thirds of their thickness on the gentle flank. It may yet be shown that the thickness of the beds at various points in an anticline varies inversely as the dip.

This question of the variation in thickness according to dip is of the very greatest practical importance in its bearing on the determination of the hade of the crest of an asymmetrical anticline. The actual hade of an asymmetrical anticline is less than that obtainable by the application of geometrical methods which do not allow for the thinning of the beds on the steeper flank. For example, the author found that in one case the hade by ordinary section construction was about 34°. Fortunately the actual hade was obtainable by correlation of wells, and it proved to be 28½°. Repeated attempts have been made to devise a method which would make proper allowance for thinning due to compression. However, the practical need for such a method is not so insistent as was formerly the case, as our knowledge of the hades of the crests of asymmetrical anticlines is likely to be

greatly increased in the near future owing to the extensive adoption of core-taking devices in the drilling of wells.

It is worthy of remark that long asymmetrical anticlines differ from domes in that they are as a rule remarkably free from dip faults. However, in many asymmetrical anticlines there is one very pronounced reversed fault on the steep flank, situated at some distance from the crest. This reversed fault usually has a big throw, and in plan it takes the form of a long gentle curve.

In the more steeply folded asymmetrical anticlines, subsidiary faults occur between the main reversed fault and the crest; in fact, this part of the structure may be a complex faulted zone. A certain amount of buckling of the gentle flank may also occur at this stage of folding.

In still more steeply folded anticlines the fault or crush zone referred to above is usually absent, and the crest is replaced by a fault, the structure having been converted into a fold-fault. In such cases the fault has an enormous throw. For example, in the Golra fold-fault near Rawalpindi the Chharat beds on the north-western flank abut against Upper Siwalik beds on the south-eastern side of the crest-fault. In this case most of the Chharat Series, the whole of the thick Murree Series, and the greater part of the very thick Siwalik Series have been cut out by the fault. Similar structures occur in Burma and Assam. They are not thrust faults, but reversed faults with a low angle of hade.

These fold-fault structures are usually very sinuous. There are several good examples of this feature in the Irrawaddy Valley and in Assam, while Dr. Pascoe has drawn attention to the sinuosity of the isoclinal folds of Ramri Island, situated on the Arakan Coast. In some of these fold-fault structures the sinuosity, combined with yielding of the beds of the gentler flanks, has resulted in the formation of secondary anticlinal spurs on these flanks.

It has been so frequently stated that oil occurs in salt domes that the statement has been widely accepted, although the relationship existing between the oil, the salt, and the structure is not properly understood. The annual meeting of the American Association of Petroleum Geologists will be held at Houston this year to enable geologists to discuss on the spot the origin of the salt bodies of the Gulf Coast Region. It is to be feared that the result may be inconclusive owing to paucity of evidence. It is unfortunate that this controversial matter could not be thrashed out in an area such as the south-eastern portion of the Fars District, near the mouth of the Persian Gulf, where a number of salt plugs are well exposed at the surface, and where the formations are also well exposed. The salt bodies of even this area have given rise to much discussion. The author is of opinion that the salt

came from a series of stratified sedimentary rocks. This view is supported by the association of the salt with gypsum, anhydrite, etc. It is perhaps wiser to refrain from comment as to the age of the salt, as controversy on this point seems to have engendered more heat than light. However, certain conclusions seem to be beyond dispute. The gentle anticlines and domes are similar to those of regions where there is no salt, and it is concluded that they were formed by ordinary earth movement. The salt occurs in the form of large circular plugs, which are in a general way related to the anticlines and domes, as they occur on or close to anticlinal axes. However, mapping has shown that the relationship of the salt plugs to the geological structure is not closer than is indicated above. For example, one of the plugs occurs at the end of a long anticline; another is situated at the side of a dome, but well away from the dome summit; while a third is situated in a saddle between two domes. The salt plugs form a minor feature of the general structure, and they do not coincide with the apices of the ordinary domes which were formed by earth movement.

It is clear that the intrusion of the salt into younger beds in the form of salt plugs was the latest geological event. Even the youngest rock formation, the Tersai Series, which is probably of Pliocene age, was folded before the intrusion of the salt. For example, the Kishm salt plug has affected the folded Tersai beds. The salt plugs are approximately circular and do not seem to have been compressed by any earth movement subsequent to their formation. The formation of the salt plugs was therefore preceded by a period of earth movement, and the salt, as it lay in its original bedded condition, was subjected to great lateral pressure. The difficulty is to explain how the bedded rock salt, under great lateral pressure, thrust itself to the surface in the form of plugs. Professor R. W. Wood, at a joint sectional discussion on Cohesion and Molecular Forces, at the last Liverpool Meeting of the British Association, described an interesting experiment. He explained that a crystal of rock salt placed in hot water can be immediately bent by the fingers, and remains deformed when removed from the water. The range of temperature over which this result has been observed is small, and the phenomenon does not occur in the case of immersion in hot oil. The fact that the fingers are used in the experiment shows that this plastic condition can be induced without the application of either a high degree of temperature or pressure. The author understands that the temperature required is about 60° C., and that at this temperature the salt becomes quite plastic and can be kneaded with the fingers. It is not known if under conditions of great pressure the plasticity can be effected at a lower temperature. It is, however, conceivable in the case of deeply buried salt beds existing under enormous pressures, that

sudden transition to a highly plastic condition might result in the salt being forced along fault-planes, joint planes, etc., and ultimately to the surface. The salt would act like a viscous lava, and would flow from a region of high pressure to a region of low pressure.

It is not proposed to discuss methods of geological mapping. It is obviously advantageous to aim at the completion of a small scale geological map or atlas to assist in forming a complete mental picture of the main geological features of a basin or belt and in studying the inter-relation of special areas. All areas of special importance should be mapped on the scale of six or eight inches to a mile. Extremely accurate topographical and geological maps are necessary for the development of oilfields, and the scale of sixteen inches to a mile appears to be suitable for most fields.

Various attempts have been made to find oil easily and quickly, and to avoid the time and trouble involved in testing by the drill the conclusions indicated by laborious detailed geological mapping. Electrical devices, which are supposed to detect buried oil pools by the resistance of the latter to the passage of an electric current, seem to succeed in measuring the resistance of the soil between the pole down which the current is sent and the second pole where the current is picked up.

The author does not propose to comment on the use of so-called divining-rods, except to point out that the connection between muscle fatigue and oil accumulation seems to be too elusive for scientific inquiry.

Perhaps the most difficult ground for a geologist to tackle is a large alluvial plain. The alluvium may be so extensive as to baffle all efforts to deduce the geological structure beneath the plain from the evidence exposed round the margin. A serious attempt has been made in recent years to obtain evidence of sub-alluvial structures by the use of the geophysical instrument known as the Torsion Balance. The Torsion Balance consists of two 30-gram weights which are balanced on the ends of an arm which is supported by a platinum wire. The main feature of the balance is that there is a vertical difference in height of 60 centimetres between the positions of the two weights. The differential pull on the two weights by an underground mass gives a twist or tort to the balance, and the amount of tort is read by means of a mirror which is attached to the wire. The instrument measures the horizontal component of gravity and the direction and intensity of the pull. At each station the balance is moved in three positions completing a single rotation. Two balances are used simultaneously as a check on each other. By plotting the values obtained, and joining points of equal gravity effect, a chart is obtained showing areas of lesser and greater density.

Torsion Balance Charts are undoubtedly interesting, and may be very useful in directing attention to special and limited "lighter" and "heavier" sub-alluvial areas. The principal difficulty lies in the true interpretation of the geological causes of the gravity effects. Furthermore, it is much easier to make Torsion Balance Charts, and to deduce the possible geological structure therefrom, than it is to prove that the geological deductions are sound. The author knows of two cases in which there is agreement between the geological structure and the evidence obtained by the Torsion Balance, and of a third case in which the correct interpretation of the concealed structure of an area was not only obtained from a Torsion Balance survey, but accepted views based on surface geological evidence situated some distance away were shown to be erroneous. The author has also studied charts of other areas in which the geological structure is still unknown, but the geophysical evidence has not clashed with geological probability. However, the application of the balance to the study of concealed geological structures is in its infancy, and our knowledge is as yet insufficient to justify the statement that concealed geological structures are reflected in Torsion Balance Charts.

When an area which apparently occupies a suitable position within an oil-basin or belt has been mapped in detail, and has been found to be favourable in regard to structure and stratigraphy, the location of the first well needs consideration. The well should be located to test probable oil bearing horizons at or close to the summit of the structure. If the well is not situated at the very summit of the structure it should be placed in the direction from which there is reason to believe that most of the oil migrated.

The location of a test-well on an asymmetrical anticline is always a very serious matter, owing mainly to the difficulty of ascertaining the hade of the crest. The beds which it is most important to test should be drilled through as close to the crest as possible, yet no serious risk should be taken of the well entering the steep flank before reaching all the beds to be tested. The thinning of the more compressible beds on the steep flank renders accurate section construction most difficult, if not impossible. This problem will doubtless be solved, at least in regard to its practical applications, by the accurate determination of the hade of the crests of many asymmetrical anticlines by a combination of accurate surface mapping with coring in wells. It should then be possible to construct a number of type sections of asymmetrical anticlines with the hade of the underground crest accurately shown on each section. Reference to the type sections should be of great value in deciding on the probable hade of the crest of a newly discovered asymmetrical anticline.

Certain scientists and inventors believe that it will yet be possible for a geologist to make his location and then send for a petroleum physicist who will photograph the contents of the strata down to maximum drillable depths, and thus dispense with the slow, laborious, and costly proceeding of drilling a test well. This suggestion seems to anticipate the future rather too freely.

What is required in the more immediate future is a drilling outfit, capable of drilling a deep test, yet which can be broken down into small parts suitable for animal transport, so as to obviate the necessity of making and keeping up very expensive roads. The tendency, however, is to drill deeper and deeper as time goes on, and this calls for stronger and heavier outfits, and consequently for good transport facilities, usually in wild uncivilised countries where roads—and certainly good roads—are non-existent.

It is not proposed to discuss drilling methods only in so far as they affect the recording of evidence of concealed strata and other geological aspects of testing and development. Geologists were formerly opposed to the rotary system of drilling owing to the difficulty of obtaining satisfactory records of the strata, and to the danger of oilsands being passed undetected. The introduction of the core barrel has revolutionised the rotary in these respects, and has converted it into the best drilling system from the standpoint of the petroleum geologist. The rotary system also possesses great advantages in respect of drilling speed and economy in casing.

The coring of oilsands is a new feature of the drilling of exploratory wells. It is most important that cores of oilsands be carefully examined, and the porosity, texture, thickness and other characters noted. The quantity of oil which seeps from a core should also be measured. Cores of productive oilsands, the value of which is known, should be most carefully studied. When new oilsands are tested, the core evidence should be reviewed in the light of the result obtained. Every effort should be made to distinguish between productive and non-productive oilsands from core evidence alone. By this means much information should also be obtained as to the characters of oilsands. The author understands that cores taken in abandoned oilfields show that oil is still present in considerable quantities in exhausted oilsands, which supports the view held by many petroleum technologists that only a portion of the oil in an oilsand is recoverable by the usual methods of development.

Rotary enthusiasts claim that any gas or water sand can be mudded off during rotary drilling. Very strong gas may repeatedly blow the mud from the hole and give much trouble before it is

controlled. Special muds are useful for this purpose, but in the case of a very strong flow it may be necessary to wait until the initial gas pressure falls before the gas can be brought under control. A strongly flowing water sand may also be very difficult to mud off, as ordinary mud placed in the hole will be washed out. In these cases also special muds will no doubt prove to be useful. It may be that almost any gas or water sand can be mudded off by special rotary muds, but it is suspected that very strong flows of gas and water give much more trouble than is usually admitted by rotary enthusiasts.

It seems to be probable that valuable oilsands will not be mudded off during the drilling of an exploratory well, as the gas pressure in the oilsands is at its highest when the sands are first pierced by the drill. The mud will probably not penetrate the sand, but will form only a thin film on the surface. However, there is no doubt regarding the fact that rotary mud fluid, and even very thick and heavy mud fluid, will penetrate partially exhausted oilsands, after the pressure in the sands has fallen to a low point. Many instances are known of rotary mud fluid having travelled from well to well.

It is unnecessary to dwell on the ordinary duties of an exploitation geologist. He must see that the geological map of an oilfield is kept up to date as fresh evidence is revealed by new roads and gradings. Contoured oilsand maps will help him to keep a close watch on the development of the respective sands. He will have to locate wells and to recommend deepening and abandonment when necessary. The fixing of depths for cementation is also important, and it is expected that the examination of cores of the strata which immediately overlie the oil sands will facilitate the selection of the best horizons for cementation, and therefore the efficient protection of the oilsands from invasion by overhead water.

There is room for collaboration between the geologist and the chemist in the work of oilfield development. Where correlation is very difficult owing to the absence of marker or key beds, it may be effected with certainty by taking into account the chemical and physical properties of the oil and water from various levels. Knowledge of the characters of the various oilfield waters may decide if overhead water has broken into a well, or if a lower water sand has been found beneath a perfectly successful shut-off. The geologist and the chemist working together can also ensure that the most suitable mud obtainable is being used in the rotary wells. Knowledge of the nature of the oil found at various horizons of the oil measures, and also at different points within the same horizons, may throw much light on the migration and accumulation of petroleum.

One would expect the lightest oil to occur at or near the summit of an oilfield structure, and the oil to become progressively heavier down the flanks and pitches. This arrangement probably holds good in some oilfields, but the author is aware of one case in which the oil in the several sands varies in character in one direction only, quite irrespective of slight changes in the dip and pitch. The oil in this particular case presumably migrated into the dome almost entirely in one direction, the lighter oil having reached the dome first and the heavier oil having been banked up against the lighter oil. Further chemical research into the lateral variation of oil may show that in many oilfields the arrangement of the oil has been determined mainly by the direction of migration of the oil into the reservoirs.

There would seem to be considerable danger of loss of oil, and also of damage to oilsands, by rapidly advancing edge-water, where production is taken from several sands simultaneously in one well. Oil may also be lost by dissipation into intercalated porous beds. McMurray and Lewis state that the subject of the waste of oil by migration to and dissipation in other strata has not received the attention that it merits. A striking case of the passage of oil through strata was provided by the famous Mexican well, Potrero No. 4. When a concrete house was built over the well to protect it from rebels, large and active seepages began to make their appearance over a large area in the neighbourhood of the well. The oil evidently found its way along some porous stratum and thence through joints and fissures to the surface.

The author is on the whole impressed with the regularity and uniformity of oilsands. Although sands were deposited as lenticles rather than sheets, this is often not strikingly illustrated within the limited area of a producing field. Of course, lenticularity does occur, but it has probably been exaggerated through placing too much reliance on the accuracy of drillers' well logs. The author has seen sections, based on drillers' logs, which have exhibited a degree of lenticularity which could only be described as fantastic. In several fields known to the author the exposed oil measures are remarkably uniform, while the concealed measures, as revealed by drilling logs, show an amazing degree of lenticularity.

In connection with the appearance of water in an oil-well, colour tests may be useful in indicating the source of the water. Fluorescin is considered to be the most satisfactory indicator. The following tests were carried out at the author's suggestion, the indicator being a methyl violet solution. Well A was producing 325 barrels of water daily, and the 8-inch string was supposed to be shutting off all overhead water. The methyl violet

solution was poured behind the water string and hourly samples of the well water were drawn and examined. The next morning sample after sample showed the colouring matter distinctly, proving that the 8-inch isolation was faulty. Well B was producing 200 barrels of water daily, and the shut off with the 8-inch string was considered to be still sound and effective. The indicator was poured behind the water string, and hourly samples of the well water were drawn off and examined for a period long enough to give the colouring matter every chance of showing up, and with an entirely negative result. While a positive result proves that overhead water is gaining access to a well, a negative result seems to have little probative value. However, in case B the water string was pulled ten days after the experiment, and the colouring matter showed up at once in the well water, thus proving that overhead water had been effectively shut off, and suggesting that some degree of reliance might be placed even in a negative result.

The above-mentioned aspects of oilfield geology are merely ancillary to the main problem of devising the most satisfactory development scheme for a property, and of seeing that the scheme is adhered to as closely as economic considerations will allow. The development scheme adopted will depend primarily on whether the property is an entire oilfield structure or is only a section of an oilfield. This distinction between oilfield properties is of great importance. It is common knowledge that there is not a single oilfield in the United States which is owned by a single proprietor or company, the oilfields being split up into blocks and sections which are exploited by competing interests, with the result that each and every proprietor strives to extract the maximum quantity of oil from his own and adjoining properties. A sectional geologist would in the first place endeavour to work out the number of locations required to drain the property. The correct spacing of wells depends on many factors, and notably on the thickness and porosity of the reservoir rock or rocks, and the viscosity of the oil. It is difficult, if not impossible, to lay down hard and fast rules as to the spacing of wells. In the case under consideration it would be wiser to risk placing them too close together rather than too far apart, particularly if the oilsands were very rich.

It is unsound practice to drain oil from many or even several sands simultaneously in one well. However, with several proved sands in a property it would be fatal to drain the uppermost sand, and then to deepen to the next sand, and so on, thus draining the sands in rotation, as adjoining proprietors would forestall one in skimming the cream off the lower sands. It is therefore advisable to drill several wells per location, and to put down one well to

each rich sand, thus ensuring that all the rich sands are drained simultaneously. However, the existence of many rich sands would seem to call for some form of limited group production.

A still more important factor is the drilling in of all the required wells as quickly as possible, so as to take the fullest possible advantage of the high initial gas pressures in the oilsands. It is the expulsive energy of the gases dissolved in the oil which forces the oil into the wells. This initial pressure falls rapidly when an oilsand is tapped, so it is advisable to drill in all the wells as quickly as possible to take the fullest advantage of the high initial gas pressure, and thus to obtain the highest percentage of the great initial production of oil which the sand or sands are capable of giving.

When an entire oilfield is owned by one company or proprietor, the main object of a development scheme is to extract the maximum ultimate production which the field is capable of yielding. The first aim of the geologist should be to test outward in order to prove the limits of the field. This is a distinct testing stage to prove the size of the productive area. It would then seem to be desirable to develop the field from the margin and to work inwards towards the summit of the structure—that is, to the dome centre in the case of a dome. The following advantages should accrue from this suggested method of development:—

(1) Damage to oilsands by secondary overhead water gaining access to them would be reduced to a minimum. Such overhead water could not damage the oilsands in the highest and best parts of the structure.

(2) This scheme of development is based on the utilisation of the hydrostatic pressure which is greatest along the margin of a field.

(3) The necessity of protecting upper oilsands while lower ones were being developed would practically disappear.

(4) Loss of gas and oil through underground migration and dissipation would be minimised.

(5) As gas tends to collect in the very highest parts of geological structures, the maximum quantity of gas would be retained in the oilsands for the longest period of time and would thus exert its full force as a propulsive agent.

(6) Edge water would slowly replace the oil extracted and thus uphold as much as possible the pressure on the oil in the sands. The slowly advancing edge water would form the most complete and effective water drive, and would

therefore obviate, or at least reduce to a minimum, the need for special and expensive methods of recovery during the final stages of exploitation.

The "life" of an oilfield depends on the quantity of recoverable oil in the field and on the rate of extraction. It is only possible to estimate very roughly indeed the quantity of recoverable oil in a field. However, the collection of a large amount of information as to the thickness and porosity of the oilsands of a field by examination of cores should help very much in the estimation of the amount of oil which is present in the oilsands.

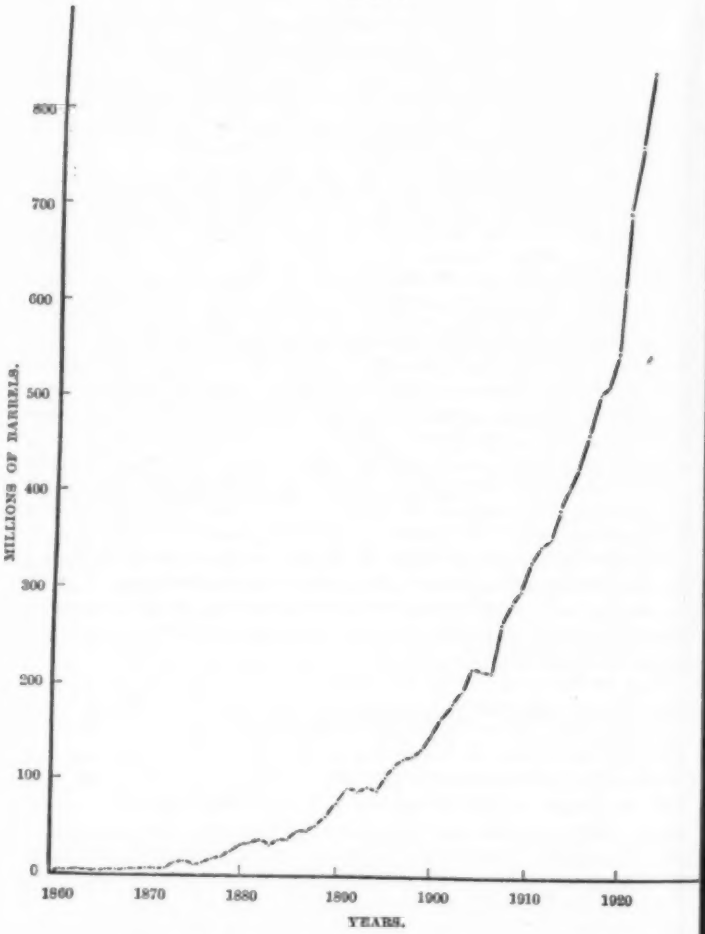
The rate of extraction of the oil obviously has a most important bearing on the "life" of a field. The porosity of the oil reservoir rock and the viscosity of the oil are most important factors in this connection. Other factors being equal, the "life" of oilfields varies inversely as the mobility of the oil. Oilfields can be roughly divided into two classes on the basis of this factor of mobility.

(1) *Limestone Fields*, in which the reservoir rock is a limestone. In these fields the oil is usually concentrated in one bed of limestone. Owing to dolomitisation, jointing, and fracturing, limestone reservoirs are usually far more permeable than sandstone reservoirs. The uppermost portion of a limestone formation is usually the richest in oil, and in some limestones it is the upper portion which is dolomitised. In consequence of this feature of permeability, the biggest oil-wells in the world have been found in limestone fields. A good example of a limestone field is provided by the Dos Bocas Ridge in Mexico. The early wells drilled in this field gave enormous productions, and the biggest well in the history of the petroleum industry was struck at the summit of the whole structure. The oil rose to a height of 598 feet, and the initial daily production was nearly a quarter of a million barrels. Owing to the mobility of the oil due to the high degree of permeability of the reservoir rock, such wells drain a very large area. As enormous volumes of oil are removed rapidly from the reservoir the pressure within the oilpool becomes reduced at a comparatively rapid rate, until at a certain stage the primary edge water, which is able to travel rapidly along the very pervious formation, rushes in to replace the oil which has been withdrawn. The invasion of the primary salt water is very rapid and even sudden, as a large field may be flooded with salt water in a matter of hours. The danger therefore always exists that a limestone field may pass quickly from a stormy but brilliant youth to a brief and precarious old age.

(2) *Sandstone Fields*. A sandstone field usually leads a steady and well conducted life. If there are many oilsands the first

generation of wells may be unable to reach the lower sands, which thus remain as an untapped reserve, particularly if the upper

FIG. 1.



sands are rich and fulfil production requirements for a long period. Again, the oil in some of the sands may not be very mobile, in which case it will take a very long period to exhaust the recoverable

oil. Sandstone fields are therefore usually more steady and reliable mining propositions than are limestone fields.

There are one or two points which can only be referred to briefly in this paper. It is probable that many oilpools were subjected to earth-movement long after the migration and accumulation of the oil had been completed, but little or nothing is known as to the effects of such movements on the oilpools. Again, several instances have come to the notice of the author which suggest that the temperatures in exploratory test-wells are higher than they are in the wells of developed fields. The temperatures in an oilfield will probably decrease with development owing to the cooling effect of gas escaping at many points over a long period of time. The primary edge waters are probably much warmer than the oilpools, as is indicated by the fact that the advent of primary salt water in a well is usually heralded by a noticeable rise in temperature.

The recent statement that the original Drake well is still producing oil provides a striking illustration, if such were needed, of the youth of the petroleum industry. Garfias gives the world's production of oil since the year 1857, and the figures for the years 1860–1922 inclusive have been plotted in the form of a graph (Fig. 1).

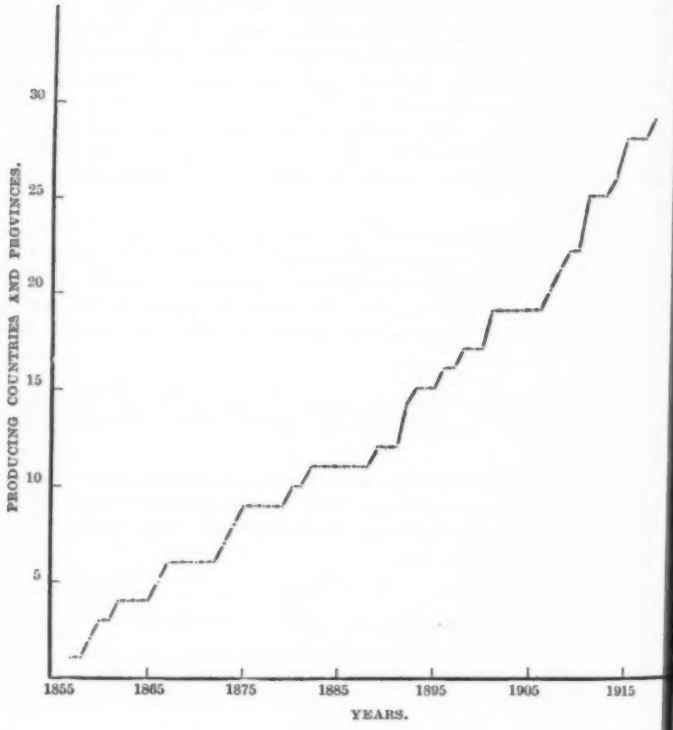
This curve shows that the growth of production has been very rapid indeed, and indicates further growth rather than early and rapid decline.

The following list shows, as far as the author has been able to ascertain, the years in which oil was found in commercial quantities in the various oil-producing countries and large petroliferous provinces :—

1857 .. Rumania.
1859 .. The Appalachian Region, U.S.A.
1860 .. Italy.
1862 .. Canada.
1866 .. Maikop.
1867 .. California.
1873 .. Baku.
1874 .. Galicia.
1875 .. Japan.
1880 .. Germany.
1882 .. Mid-Continent Region, U.S.A.
1889 .. Burma.
1892 .. Sumatra, Upper Assam.
1893 .. Grozny District.
1896 .. Peru.
1898 .. Dutch Borneo.
1901 .. Mexico, Gulf Coast Region, U.S.A.
1907 .. Argentina.
1908 .. Trinidad.
1909 .. Persia.
1911 .. Egypt, Sarawak, Emba District, Russia.
1914 .. Venezuela.
1915 .. The Punjab, Lower Assam.
1918 .. Columbia.

This list merely shows that the opening up of oil-bearing countries and regions has proceeded very steadily. In fact, this steady progress is somewhat remarkable, as is shown by the following curve :—

FIG. 2.



New oil-bearing countries and large petroliferous provinces will undoubtedly be added to the list in course of time.

If it were possible to prepare a list giving the dates of the discovery of individual oilfields it would probably be shown that the rate of discovery of new fields is now greater than was formerly the case. This result is even suggested by comparison of Figures 1 and 2, and is the natural outcome of the growing inducement to

open up new pools in proved oil-bearing regions within the period under review.

The problem of the world's future supplies of petroleum should be viewed very broadly. It should be remembered in this connection that petroleum was formed throughout the greater part of recorded geological time and in many parts of the world. It seems to be most improbable that the whole of this petroleum can be discovered and withdrawn within a brief period.

It should also be borne in mind that petroleum geology is still in its infancy, and that advances in the science will provide the best assurance that deposits of petroleum of commercial value will not lie undetected and undeveloped.

The above remarks apply to petroleum supplies and prospects in general. Of the sources of supply within the British Empire there are developed oilfields in Burma, India, Sarawak, Trinidad, and Canada, and attempts are being made to extend proved areas and to find new oilfields in these countries. Keen interest is also being taken in the possibilities of finding petroleum in commercial quantities in Australia (including Papua and Tasmania), New Zealand, South Africa, British North Borneo, Barbados, Nigeria, and the Gold Coast. It may therefore be taken for granted that every effort will be made further to prove and develop the oil possibilities of the Empire. It is to be hoped that these efforts will be crowned with success, as the present production within the Empire not only constitutes a very small percentage of the world's total production, but is quite inadequate to meet even the present requirements of the Empire alone. The American Petroleum Institute estimates that in 1923 the United States produced 735,000,000 barrels, or 72·7 per cent. of the world's production, and that the British Empire produced 14,725,000 barrels, or only 1·42 per cent. of the total. These figures show that the weekly production of the United States approaches the yearly production of the whole of the British Empire. It is therefore necessary to face the fact that this great Empire is dependent on foreign sources of supply.

The Chairman said he always found that when the questions of the origin and migration of petroleum came under discussion, it was something like raising the questions of cement and concrete before the Institution of Civil Engineers, so many different opinions being held in regard to them. He hoped the discussion would be an interesting one.

DISCUSSION.

Mr. T. G. Madgwick, in opening the discussion, thought the author had presented a paper in which he had so successfully condensed the subject that it almost seemed a pity to expand again the material contained therein. A difficulty that arose in presenting a résumé of such a nature was that generalisations might be made which were too sweeping. There were, *e.g.*, one or two details in the paper with regard to Russia which called for comment. For instance, reference was made to the occurrence of rock salt in Baku. As a matter of fact, there was no rock salt actually in or near the Baku field, the only local occurrence being in the form of salt lakes. In the Table at the beginning of the paper the author had not put the occurrence of Baku oil in the Pliocene system but in the Miocene, which was incorrect. The Pontian formation was the principal producing formation there.

Further, he doubted whether the statement made that the biggest oil wells in the world had been found in limestone fields was a demonstrable fact. The question of the world's biggest well was difficult to determine, because in so many cases the oil had been lost. Although the author doubtless had Mexico in mind, which had produced very large quantities of oil from limestone under conditions so far unique, some of the Baku wells had been really greater. Much of the oil, however, in some of the big Baku gushers was lost by fire or in other ways, so that the production had not been determined. He knew of a well there which produced for twenty-eight days through 18-inch casing, and up to its collapse was flowing as freely as when it started. That well, the entire production of which was burned, must have given a greater quantity of oil than any of the Mexican wells.

He thought the author was to be thanked for calling attention to the peculiar property possessed by rock salt, namely, that its crystals could be bent at a certain temperature. That had an important bearing on the supposed flexibility of rock salt in nature, although it was possible that rock salt might not itself be as flexible as some geological sections suggested. In many cases alternating beds of rock salt and shale had been deposited; the shale beds during movement played the part of a lubricant and were squeezed out, inducing enormous stresses in the rock salt which was then bound to accommodate itself by crushing and recrystallisation. An instance of how that had happened occurred in the Slanic Mines in Rumania, where the salt with included "dirt beds" could be traced in the form of an over-fold.

Mr. H. B. Milner said he desired to refer to the statement the author had made in his paper with regard to Huntington

Beach, a slight correction of which had since been made when introducing the paper. When he (the speaker) was over there in the previous year, there was considerable difference of opinion as to what the structure actually was at Huntington Beach, and one opinion held was that no actual anticlinal crest had been proved. He thought recent research had shown that the oil was accumulated there on what the Americans called a monocline—*i.e.*, a change of dip, and that if that was part of a definite fold, the axis of the fold lay out to sea. The accumulation of oil under such monoclinal conditions was a very important factor in the United States. He thought it was the only case in the Los Angeles Basin where such an accumulation had taken place, but if that were so, there might be other possibilities of a like nature within that basin. He desired in the next place to call attention to one of the last paragraphs in the paper, in which the statement was made :—" It should also be borne in mind that petroleum geology is still in its infancy, and that advances in the science will provide the best assurance that deposits of petroleum of commercial value will not lie undetected and undeveloped." He felt that both now and in the future geologists should not be content merely to study the fields to which they were sent, but that they should give a lead to the industry in one particular direction—*i.e.*, in regard to the places where it was no good to search for oil. He thought it would be agreed that there was a definite science underlying the principles of geographical accumulation of oil as distinct from merely local accumulation, and that it was useless to equip a large expedition to go into the heart of, say, Northern Canada, where the Canadian shield existed, or into the heart of Brazil, where the Brazilian shield existed, or into the central parts of Africa. If a little more attention were paid to the fundamental elements of the evolution of the earth's crust, in so far as its rocks were concerned, to accumulation and migration of petroleum particularly in geotectonic belts, and to the relation of the oil-zones to such tectonics, it would limit the possible areas in the world in which commercial deposits of petroleum were likely to occur. He thought geologists should give a lead in that direction to those who were responsible for initiating the explorations, for after all that was essentially part of the geologist's work. It would be increasingly important in years to come to find new oilfields, if possible within the British Empire, and he felt that this was one of the most important duties of the geologist.

Mr. W. C. Simmons said that he came from the Uganda Protectorate in the centre of Africa, and represented Mr. Wayland, the Director of the Geological Survey of Uganda. The previous speaker had just stated that there was no possibility of any oilfield

being developed in the centre of Africa, presumably because on the geological maps of the British Empire that portion was shown as a field of Archæan rocks or granite. He desired to call attention to the fact, however, that in the big rift valley of Lake Albert there was an oilfield, although its value had not been proved. There was a big series of Tertiary rocks lying in the Lake Albert Rift Valley which were being investigated by Mr. Wayland in Uganda, who hoped shortly to publish the results of his investigations. He therefore desired to make the plea on behalf of Uganda that it be not written off as an impossibility before the investigations that were being carried on were completed.

Mr. A. Beeby Thompson said he desired to add a few remarks upon the subject of oil zones. Those associated with oilfields always kept in mind the association of oilfield belts with geo-synclines. The great geo-synclines of the world were known, and outside America the oilfields of the world were closely allied with those geo-synclinal areas. Large parts of the globe could be excluded from oil-bearing regions as being composed essentially of nearly stationary continental masses. There were exceptions requiring investigation, such as Uganda, where there was a curious development of oil rocks round Lake Albert. Explorers from Central Africa state signs of oil are pronounced. Until the region had been minutely examined geologically, however, it could not be said whether the conditions favour the formation and accumulation of oil in commercial quantities. In the search for oilfields geologists kept away from the disturbed mountain areas and confined their investigations to low foot hill country where inflections were less severe. Some of the great oilfield belts are of enormous extent, as, for instance, that stretching from Assam down to Burma and round the East Indies to New Guinea. Some of the Palæozoic fields occurred under somewhat different conditions, but they constituted such a small proportion of the oilfields of the world, viewed from a geographical point of view, that they did not modify the geo-synclinal theory. Oilfield geology is viewed from a much broader aspect than formerly now that scattered information is being collected and correlated, and future work will be greatly simplified by the exchange of data from far separated countries.

Dr. J. A. L. Henderson said he felt strongly that geologists who had to search for oil should, as part of their course of training, undertake practical oilfield work in order to fit themselves properly for interpreting the phenomena which they observed, and for exercising their appropriate functions in the direction of the work of exploration and exploitation.

He was interested to note the author's remarks on the frequent occurrence of marked fissuring or faulting in productive oilfield structures, and, in particular, on the presence of numerous mud-filled dykes in the chief Burma oilfield. The experience during recent years on many of the most important oilfields in North America and the West Indies showed the need for most careful study of faulting and fissuring conditions, not only in relation to their often paramount influence upon the concentration of oil in commercial quantity, and probably upon the quality of the mineral, but also in regard to the proper methods of exploitation which should be adopted. Fissures are found filled not only with barren mud or rock, but also with solid or plastic bitumens, liquid oil, oil-saturated sand, and water; and it is a matter of surprise that fractures of considerable width, extending over thousands of feet in length, and hundreds, indeed thousands of feet in depth, in soft Tertiary argillaceous beds, can remain open for such long periods as will allow of the deposition and consolidation of repeated generations of bitumen, or for their injection and filling from below by soft sands and clays. He thought that feature had not hitherto received the study which was warranted by its importance.

Mr. T. Dewhurst, in reply, after thanking the speakers for their interesting comments and criticisms, said that Mr. Madgwick had explained that rock salt did not occur in or close to the Baku field. The statement in the paper that the district of Baku was formerly highly esteemed for its rock salt referred to the past, and to the district rather than to the oilfield. Moreover, the statement occurred in Redwood's standard work and, therefore, deserved careful consideration. However, Mr. Beeby Thompson's statement in his "Oil-Field Development" that in the Ural-Caspian area of Russia massive rock salt occurs in the oil belt would serve equally well as an illustration. With reference to Mr. Madgwick's statement that the petroleum of Baku belonged to the Pliocene system, and not to the Miocene, as stated in the table at the beginning of the paper, this seemed to be a somewhat doubtful point, as the authorities on the subject, including Mr. Madgwick, seemed to agree that the oil was not indigenous to the Pontian formation, but was secondary and had been derived from older beds. In regard to the contention that some of the Baku wells had been bigger producers than the Mexican well referred to in the paper, Mr. Madgwick had not submitted any figures in support of his opinion, because the productions of the Baku wells were unknown. It was therefore difficult to understand and to cope with the contention that although the productions of the big Baku gushers had not been determined, they were greater than the production of the Mexican well. In support of his statement in

the paper the author would draw attention to Sir Robert Waley Cohen's reference to a certain Mexican well as having been the world's biggest well. In his introductory remarks he (Mr. Dewhurst) had referred to a very recent report issued by the California State Mining Bureau on the Huntington Beach field. Recent mapping in the neighbourhood of the assumed crest had raised doubts in the minds of the authors as to the anticlinal structure of the field. Mr. Milner had pointed out that during his visit to the field there had been considerable difference of opinion regarding the structure. According to the latest view, the retention of the oil was due to a combination of terrace structure and marked lenticularity of the oilsands. He was in complete agreement with Mr. Milner's further remarks, and thought that Mr. Milner could rest assured, in regard to exploratory search for new fields, that geological advice based on the sound general lines he had laid down would be readily followed. It was interesting to learn from Mr. Simmons that Tertiary oil-measures had been discovered in Uganda, and it was to be hoped that the geological work now in hand would lead to the discovery of one or more oilfields. The author noted with pleasure that Mr. Beeby Thompson was apparently in agreement with the main conclusions of the paper, and particularly with that section dealing with the distribution of petroleum with reference to large geo-synclines. Dr. Henderson's remarks were very interesting, but were confined to a subject which was not dealt with in the paper, and, therefore, could not be construed as criticism. Very little was known regarding the migration of oil by fissures and crevices, and it seemed to be advisable to adopt a very cautious attitude on the subject. It was open to doubt if fissures and crevices could remain open at considerable depths in view of the high rock pressures which must exist, while if fissures and crevices occurred at shallow depths they might be merely features of certain beds of a series, and therefore have no great vertical extent. This latter view would seem to be supported by the statement in Day's recent work that "crevice oil" is believed by many to be indigenous to the beds in which it is found. The author suspected that there was not a sufficiently strong foundation of fact and evidence to justify the view that fissures often had a paramount influence on the concentration of oil in commercial quantity. The subject had not yet passed out of the purely speculative and conjectural stage. There had been much discussion of the geology of Persia since the paper was written, and recent work confirmed earlier views that the Lower Fars beds, which yielded copious seepages of oil, were deposited under desiccative inland sea conditions. It was possible, and even probable, that these conditions obtained prior to the deposition of the Lower Fars beds. This recent

research therefore supported the views submitted in the paper in regard to the conditions under which oil measures were deposited.

(A cinematograph film was then shown depicting the history of the oil industry of Burma.)

The Chairman said the thanks of the Meeting were due to Mr. Dewhurst for the very valuable paper he had presented, and also for the interesting film he had just shown, which illustrated in an admirable manner how, in a comparatively short space of time, a vast enterprise had been evolved from a very small beginning.

The resolution of thanks was carried by acclamation and the Meeting adjourned.

Wednesday, June 4th, 1924, at 2 p.m.

Mr. ASHLEY CARTER, A.M.I.Mech.E., Member of Council of the Institution of Petroleum Technologists, in the Chair.

The Evolution of Oil-Well Drilling Methods.

By A. BEEBY THOMPSON, O.B.E., M.I.Mech.E., M.I.M.M., F.G.S., M.Inst.P.T., etc.

MODERN drilling methods are in a revolutionary stage owing to the continuous call for deeper and deeper wells and quicker means of reaching the oil sands. In many cases the larger individual productions per well obtained in the deeper fields have to some extent compensated for increased drilling costs; but unless future deep development is going to be confined to very prolific pools or parts of pools, much oil will have to be abandoned unless higher oil prices neutralise increased drilling charges. Deeper and more costly drilling is enforcing more rational spacing of wells, and this in itself may favourably influence ultimate extractions per well and per unit of area.

The evolution of drilling systems has, indeed, been an interesting study. Processes have been developed to meet changing conditions in far separated countries, where the idiosyncrasies of labour, the vagaries of climate, and peculiarities of strata have influenced design and methods. Where labour was cheap and plentiful, or where to-morrow and not to-day was the watchword, or where "Kismet" was the excuse and explanation of the fatalists for everything, it is unlikely that progress should be as quick as where a tireless, ambitious, energetic, race got to work with only thoughts of the present.

Perhaps the earliest drilling tools were the Chinese wooden rods and iron bits, from which developed the Pole Tool system in its varied forms, the most popular type of which became generally known as the Canadian system. It is interesting to note that the original tools which drilled Drake's well—the first ever drilled for oil in America—are of this type and on view at the Exhibition. This process was developed in the early petroleum operations in Ontario, Canada. Before, however, describing the process of

evolution it might be well to give a general classification of the systems in use :—

Principle.		System.	When used.
Percussion.	Pole tool.	Ash poles or Iron rods and jars.	Used where alternations of hard and soft steeply-dipping strata call for under-reaming and maintenance of shoe close to bit owing to caving, and to maintain straight hole.
		Iron rods and freefall.	Used mainly in Russia where soft caving ground, many water sands to exclude separately, and large diameters required.
	Cable.	Manilla cable.	For moderately deep wells up to 2000 ft. where dry drilling possible and strata compact and hold up well.
		Steel wire cable.	For deep wells or where heavy column of fluid has to be maintained to support caving walls of hole or overcome gas.
Hydraulic Percussion.	Cable flush.	Circulating (swinging spider) system.	Employed in loose sediments where necessary to carry casing and maintain high fluid level as well as keep column in motion.
		Circulating system (reversed flush).	Used with advantage where drilling in large hole that reduces velocity of flush.
	Flush hollow rods with short and rapid reciprocating movement.	Hollow rods with internal flush.	Used in soft unconsolidated sediments with hard streaks that have to be reamed to keep shoe close to bit.
		Hollow rods with reversed flush.	Advised when it is desired to obtain good samples of strata.
Attrition (hydraulic) rotary.	Disintegrating	Rotary drills with flat, chisel, disc or roller bits.	Suitable for soft strata where long distances can be drilled without lining tubes, thus removing necessity of underreaming. Rock can be penetrated with roller bits.
	Core drills. (rotary).	Diamond drill.	Satisfactory in hard compact rock.
		Chilled shot.	Replaces diamond where there is a danger of lost crown in uncertain ground.
		Tooth crown drills.	Adopted where strata only moderately hard or soft.

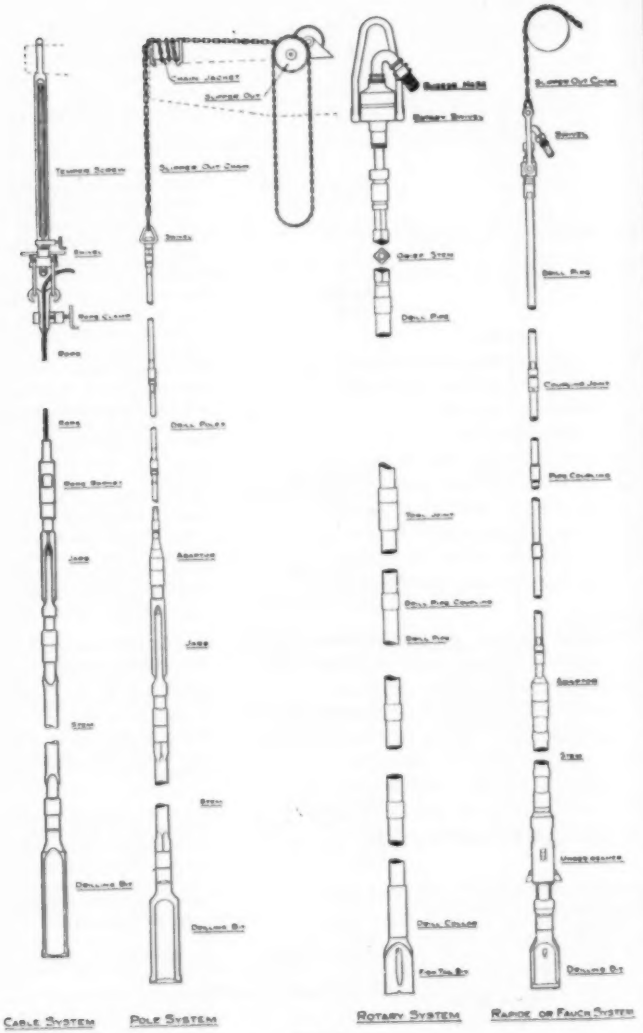
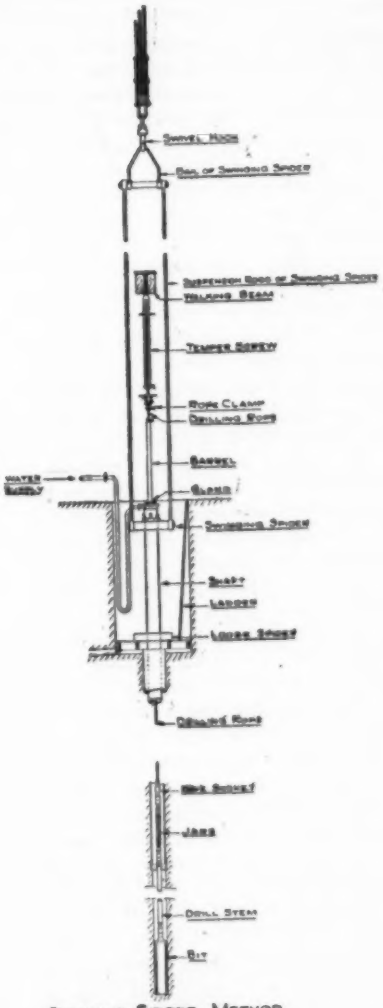

Tripod Screw
Swivel
Rope Clamp
Rope
Rope Socket
Jars
Stem
Drilling Bit
Chain Jacket
Slipper Out
Slipper Out Chain
Swivel
Drill Pipes
Adaptor
Jars
Stem
Drilling Bit
Rubber Hose
Rotary Swivel
Quad. Stem
Drill Pipe
Steel Joint
Drill Pipe Coupling
Drill Pipe
Drill Collars
Fishing Bit
Slipper Out Chain
Swivel
Drill Pipe
Coupling Joint
Pipe Coupling
Adaptor
Stem
Under reamer
Drilling Bit
Cable System
Pole System
Rotary System
Rapide or Fauch System

FIG. 1.



SWINGING SPIDER METHOD

FIG. 2.

Figs. 1 and 2 show the tools and connections used in the various systems.

Percussion Tools.—The old Canadian pole tool system is suffering a lingering death. In Galicia alone is this system still persisted in for deep wells. Here it is being used for drilling wells to a depth of 5000 to 6000 feet, an operation which occupies about three years. For moderate depths, the system has been commonly favoured, as it permits of positive acting tools in a way unapproached by any other process. Drilling and under-reaming can be carried out simultaneously when rods are used, thus enabling casing to be carried whilst drilling. The method also facilitates the employment of eccentric bits, thus entirely avoiding the use of under-reamers, whilst allowing the casing to move freely. Sharper edged bits are used than are possible with cable tools, as the positive rotation of the tools enables a cutting rather than a pulverising action to take place. The tools are worked in conjunction with jars, iron rods replacing the ash poles originally used.

The freefall modification of the pole tool process was mainly practised in the Baku oilfields of Russia, where operators were faced with exceptional drilling difficulties. Owning to the soft, loose, caving nature of the strata, no column of tubes could be carried more than a few hundred feet, and this fact, together with the prevalence of water sands needing exclusion, made it necessary to reduce the diameter repeatedly and proceed with a smaller size. For wells with starting diameters of 30 to 42 inches, with the added necessity of being completed at a depth of 1500 to 2500 ft. with 8 ins. to 12 ins. diameter casing to permit of bailing, this system was peculiarly suitable. Rods of $1\frac{1}{4}$ in. square iron were used instead of the usual $\frac{7}{8}$ in. to 1 in. round iron poles employed in Galicia, and the heavy flat bits, weighted with a sinker, were jerked loose from the freefall at the top of each stroke of the beam, from which they were suspended by means of a temper screw.

The chief objections to the use of pole tools are the frequency of fractures through crystallisation of the metal rods; the large number of joints that have to be made and broken and consequently the long time taken to raise and lower the tools; the serious accidents occasioned by a long distance drop of tools and rods and the extra labour and dangers involved in making and breaking so many joints after but a few feet of drilling.

Cable drilling has almost entirely superseded pole tool work. At first only manilla cables were used, and these are superior to wire cables for moderate depths. No process gives more rapid or satisfactory work where the ground is compact, fairly hard and friable, and does not cave; and where drilling can be continued in a dry hole, *i.e.*, with only sufficient water to make a puddle for easy

removal in bailers and sand pumps, speeds of 100 to 200 ft. daily to a depth of 2000 ft. are not uncommon.

Wire cables are used when drilling has to be continued in a long column of fluid, or in very deep wells where the elasticity of a manilla cable becomes nearly unmanageable. Until a depth of a few hundred feet is reached, the wire cable lacks that resiliency which alone renders cable drilling effective.

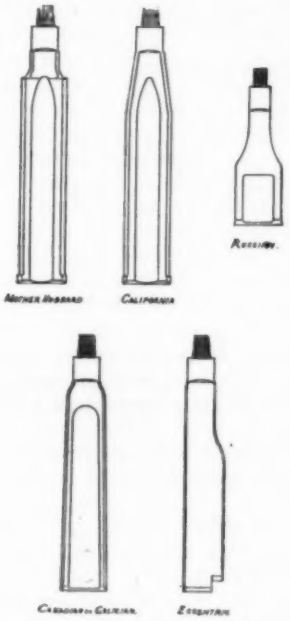


FIG. 3.
PERCUSSION BITS.

The bits for cable drilling differ from those of the pole tool process in being broader and dressed almost flat at the "working" face. They do not, in fact, have a true cutting edge, but merely a flat surface that pulverises the strata rather than cuts it. Above the bit is a sinker to give added weight, then come the jars followed by the rope socket. Cable tools can only be successfully worked by a delicate adjustment of the speed and nice balancing of the engine flywheel to suit the depth and every change of formation. Manilla cables of $1\frac{1}{2}$ to $2\frac{1}{2}$ in. dia. are used and steel cables of $\frac{7}{8}$ in. to $1\frac{1}{8}$ in.

The bits used in percussion drilling are shown in Fig. 3, and types of under-reamers in Fig. 4.

Hydraulic Percussion.—In an effort to overcome some of the difficulties inseparable from the use of pole tool or cable systems which necessitate the frequent removal of the tools in order to

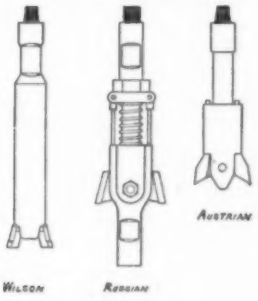


FIG. 4.
UNDER-REAMERS.

clean out the pulverised débris, circulating systems were designed. They were specially developed in California to deal with caving and resultant casing troubles occasioned by the unconsolidated tertiary sediments.

The first attempt in this line was to circulate mud fluid down the well and up behind the casing whilst the drilling tools were working

FIG. 5.
HYDRAULIC-PERCUSSION BITS.

on a wire line that passed through a gland and stuffing box on the casing head. The freedom of the casing was maintained by a so-called swinging spider—two long links, that passed one on either side of the beam, connecting the swinging block with the spider that supported the casing in the shaft (Fig. 2). It was thus possible to continue drilling whilst the cuttings were being flushed to the

surface, and the casing could quickly be put in motion at frequent intervals without withdrawing the tools. Much longer strings of casing could be carried and set in this way than formerly, and the results opened the eyes of operators to the advantages of a mud fluid as a supporter of the walls of a well. At a later date reversed circulation was sometimes adopted, whereby the fluid was pumped down the well between the working column and the next larger diameter, causing the return fluid to overflow at the casing head. By this means there was less trouble in maintaining circulation, as all the pulverised material rose in the casing instead of in an annular space. This method, however, entails more elaborate surface gland and stuffing box attachments between the casings to allow the collars of the working column to pass. Both circulating methods led to a great economy in casing and a reduction in the time usually spent in freeing columns.

European operators sought to combine a fluid flush with percussion tools, but being sceptical of and unfamiliar with cable systems, and desiring positive movements, they carried their bits on tubing or hollow rods, giving the tools short rapid strokes, whilst pumping water through the rods under pressure and turning by hand. In the numerous designs of this type motion is transmitted in a variety of ways, sometimes by means of cams or eccentrics, as blows at a rate of from 50 to 150 per minute are usually delivered. Elaborate shock absorbing arrangements are introduced at several points to take up the violent shocks, which would be otherwise transmitted to the rods and working frame. A very heavy sinker, nearly filling the hole, is at times used to impart weight and guide the bit straight.

When it is desired to obtain cores a reversed flush is employed by forcing down the fluid between the drill-tubes and the casing and returning it to the surface through the drill-pipe with the cuttings. In such cases it is necessary to use special serrated bits with a central orifice slightly smaller than the bore of the tubular rods, through which the cores of the strata are ejected with the return flush.

These flush rod methods perform quite good work in soft strata disposed to cave, or in moderately compacted beds, but the speed is slow in hard strata, and the average rate is usually slower than by other methods. Crystallisation of metal is the cause of frequent breakages of the hollow rods, the recovery of which is, however, rarely complicated with difficulties. There is, obviously, some saving in casing owing to the greater ease with which casing can be carried when a full column of fluid is maintained. Very short stubby bits are usually used, often of the eccentric type, except in the smaller sizes, where the sinker nearly fills the casing.

Various bits used in this system are shown in Fig. 5.

Attrition Drills.—By far the most revolutionary change in drilling has been caused by the rotary flush attrition drill. Steadily and unceasingly improved by additions to weight, increase of strength and refinements in design, the system is rapidly replacing all others for unconsolidated strata or even compacted strata if not too hard. The drill is too well known to call for detailed description, and it is only necessary to refer to certain features. Owing to improvements in steel manufacture, fish tail bits are being made to cope with harder and harder material. Although special bits

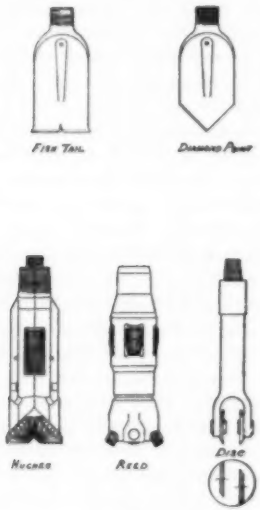


FIG. 6.
ROTARY BITS.

are made for hard rock, conglomerates, and for specially soft sediments, the fish tail bit is holding its own. Fig. 6 shows types of these bits. Next in importance have been the improvements in drill-stems and their joints. By using 19 lb. drill-pipe with special up-set ends and heavy tool joints, the chances of twist-offs have been materially reduced. Amongst the other important improvements may be mentioned (1) weight, size and shape of drill-stem to diminish punishment when rotated; (2) development of hydraulic swivels to carry the weight of drill-pipe and tools; (3) use of heavy steel hoisting gear; (4) changes in mud pumps; (5) employment of twin-cylinder steam engines for the drive; (6) increased knowledge of muds.

As is well known, the rotary flush drill depends upon the attrition of the strata by a rotating steel bit, upon the face of which impinges a powerful jet of mud, which clears its path and carries the cuttings to the surface. Drilling is conducted in an open hole, commonly made about 3 to 4 inches larger in diameter than the outside of the casing it is intended to insert. Only whilst the bit is being raised for renewal is the circulation of mud suspended until it is desired to set a column of casing. An initial column is generally set at a few hundred feet and cemented in position to avoid serious troubles in the event of an unexpected blow out of gas or oil.

Some of the advantages of the rotary flush drill are : (*a*) the few weak parts below the surface, (*b*) the constant action of the bit instead of periodical blows as in percussion methods, (*c*) the automatic removal of cuttings, and the plastering of the sides of the hole by the rubbing of the drill-pipe on a lubricated surface, (*d*) the saving in casing through being able to bore long distances without lining, (*e*) the simplicity of processes for water and gas exclusions or mudding off gas or water sources, (*f*) the very rapid progress in suitable strata.

The weak features of the rotary are : (*a*) the tendency to produce a crooked hole or leave projections through the bit working its way round obstructions, thus necessitating for rapid work the drilling of much larger holes than by other systems for a given diameter of casing, (*b*) the costly nature of the operations in power and often the water and mud needed for the work, (*c*) the heavy labour bill.

As in other forms of drilling the avoidance of trouble largely depends upon skill and judgment in manipulation. By careful handling of the hoisting gear brakes and engine control, the descent of the bit can be modulated to secure effective progress without hazarding a twist-off by undue torsion. As with cable drilling, rapid wear takes place on the edges of the bit, thus causing a gradually tapering hole, entailing reaming with a newly dressed bit before bottom is reached.

Holes are sometimes reamed with star bits when a jagged face is left, where passing a succession of hard streaks between soft beds ; but, perhaps, the best plan is to use a fish tail bit on a few lengths of the casing it is intended to insert, at the base of the drill-pipe, so that the bit is guided to plane off crooked strips or obstructing edges.

When a rock is reached which cannot be negotiated with a fish tail bit one of the roller bits is used. These bits have rollers with serrated edges, which under pressure crush the rock face and gradually pierce the bed. In some cases where there are considerable thicknesses of hard beds between soft shales, it is a common practice to have a combined rotary and percussion rig, so that the percussion tools can be used where the strata are suitable.

To a depth of about 3000 ft., 6 in. drill-pipe is generally used, but at greater depth the weight is excessive, and it is usual to employ 4-in. drill-pipe. Derricks 120 ft. high are used to enable strings of four pipes, 96 ft., to be pulled at a time, so quickening the time of raising and lowering and reducing the number of tool joints.

Core drills have always been largely used for mining operations, where it was often essential to obtain undisturbed sections of the strata, but the cores are of small diameter and taken in hard rock. These small drills usually have diamond crowns, and the core is preserved in a core barrel around which the water flush circulates and carries away the debris. When core drilling in large diameter wells, the diamond crown is invariably replaced by an annular toothed cutter or a slotted steel crown beneath which chilled shot is introduced through the medium of the circulating water. The Calyx drill is one of the well-known steel cutter crown types; but chilled shot is very commonly used for drilling in hard rocks.

Unless there is some particular reason for obtaining cores, as in metalliferous mining, there are no obvious virtues in core drills. They necessarily incur complications it is better to avoid, and it is only in hard rock or very compact strata that good cores can be obtained in deep wells. The increasing demand for specimens of strata from deep wells at specific depths where the use of rotary flush methods tends to obliterate characteristics, is leading to a demand for core-extraction apparatus which can be attached to ordinary plant.

Pilot holes are often now cored in interesting formations at selected depths to test ahead for dip, oil content, and nature of the beds for setting casing, etc., etc. For this purpose it is usual to attach an annular cutter and core barrel and cautiously rotate for a given number of feet, before breaking the core either by grouting with some crushed brick or ashes, or by means of some automatic contrivance. Where the strata is very soft it is necessary to have a second stationary internal chamber to receive and protect the core from the circulating fluid. Samples, in contradistinction to cores, are frequently taken by improvising a circular cutter from a length of drill-pipe. The teeth are turned slightly inwards and after very cautiously rotating with light weight for some distance without flushing, increased weight is allowed on the teeth, causing them to turn inwards and hold any sample which has entered the tubing.

Hydraulic methods of drilling are certainly calling for a revision of sampling methods. The behaviour of the drill will enable a keen intelligent operator to note changes of strata, and by experience to distinguish types of formation, but those less observant may misinterpret events and may lead the geologist astray. When a clean mud is used all fragments in the return fluid represent cuttings, which if collected in vessels placed at the outflow or collected on

riffles along a chute and systematically removed, will give a good idea of changes of strata. Bubbles of gas or films of oil on the return fluid are generally recognisable at a glance. At times, however, there are losses of mud, and oil sands may be mudded off without betraying their oil or gas containing property to the operator. It is to diminish this risk that cores are so often demanded at interesting junctures. There is undoubtedly a risk of missing gas or oil strata, where petroliferous beds do not show up readily, and this danger is now generally admitted by the demand for cores at momentous depths.

Not only have deeper wells made modified methods of drilling essential, but equally important have become the problems of casing for lining the wells and processes of isolating water and protecting casing from corrosion. Increased thickness involves the handling of greater weight, and if the use of many successive sizes is to be avoided, columns must be relieved of wall friction by only inserting strings of casing after the hole has been prepared to a seating. The present practice, of lowering the column only after drilling to the desired depth, removes this one objection of friction, and the next problem is the provision of sufficient strength to avoid collapse by external pressure, for at depths of 5000 ft., the outside pressure may reach 2500 lbs. per sq. in., if the well is relieved of all liquid. The danger of collapse can be greatly diminished by cementations, which re-enforce the walls, strengthen up the lining and protect the metal from corrosion. But even cementations must be conducted with great care to ensure a fairly equal distribution of cement around the casing. That is, wells must be vertical and the sag of the column taken up by relief of weight after being seated.

So long as there is a counter-balancing pressure in the casing through maintenance of a high fluid level, no danger of collapse exists, but with exhaustion of oil, and no replacement by water, the full pressure due to static head of excluded waters must be thrown on the pipe, and this, too, at a time when it has, perhaps, been weakened by internal corrosion, if not external. In many fields the static pressures of all fluids in an oilfield are reduced concurrently, either through excluded water working its way into the oil strata as depletion proceeds, or by suffering gradual relief of pressure.

Notwithstanding higher working costs, the cost of deep rotary wells is cheaper than by other methods on account of the fewer and simpler accidents, the fewer times it is necessary to remove the bit for re-dressing than in percussion methods, and the saving of all handling of casing until the column is finally inserted, set and cemented. In an ordinary percussion drilled well, half the time is occupied in keeping the casing free and adding new joints. Long distance transport of casing over difficult country is often a serious

item where many strings are required frequently only as a temporary expedient.

No useful purpose would be served by pretending that the working of the rotary presents no difficulties. In every new field

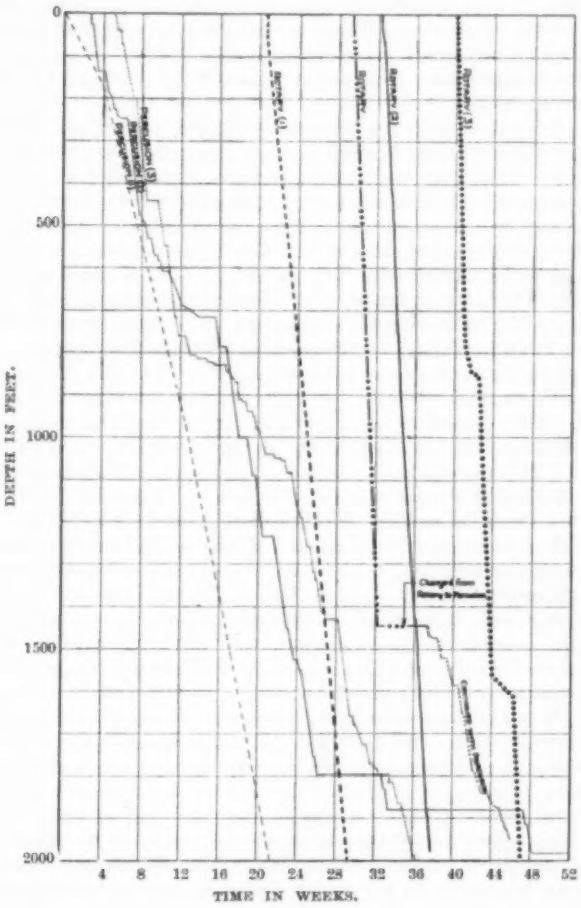


FIG. 7.

GRAPHIC REPRESENTATION OF DRILLING SPEEDS SHOWING COMPARISON OF PERCUSSION AND ROTARY METHODS IN THREE DIFFERENT FIELDS, AND IN ONE WELL WHERE PERCUSSION METHODS FOLLOWED ROTARY. THE NUMBERS 1, 2 AND 3 APPLY TO WELLS IN THE SAME FIELD.

known to the author, into which it has been introduced, with the most skilled operators, selected often by the manufacturers of the plant, difficulties and troubles have been experienced, and much delay occasioned before reasonable progress could be made. Hard

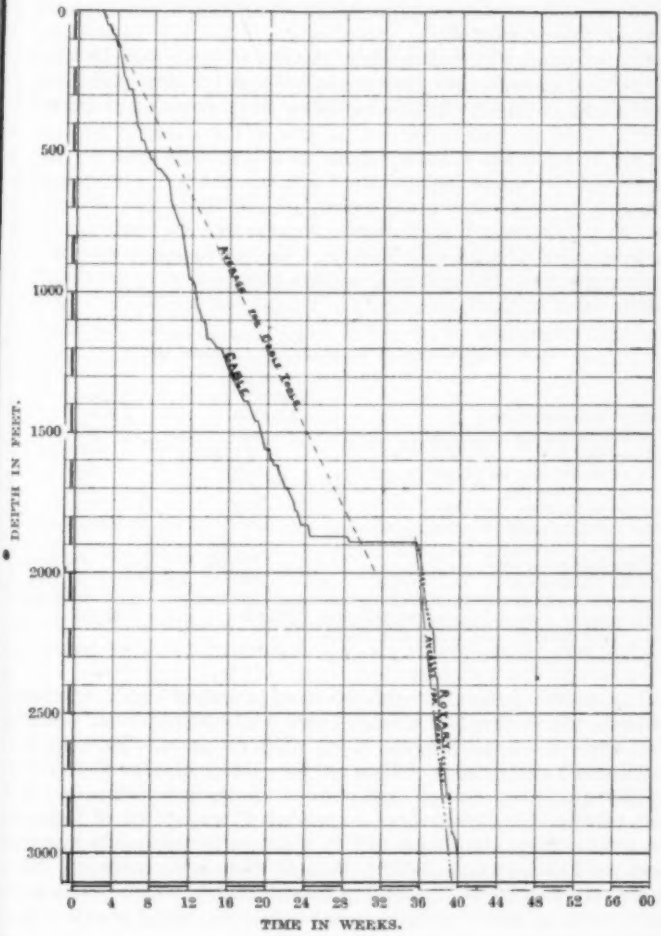


FIG. 8.

GRAPHIC REPRESENTATION OF DRILLING SPEEDS OF PERCUSSION AND CABLE DRILLING IN A 3000-FT. WELL.

streaks, boulders, inclined strata, loss of fluid in sands or crevices, at times present great difficulties and cause many twist-offs. In the penetration of a single hard sandstone but a few feet thick, a dozen bits may be ground to a stub end. Until the peculiarities of a region are ascertained by actual tests, failures and half successes are likely to cause doubts to be cast on a process that will eventually prove highly successful.

One case can be recalled where the use of the rotary had to be abandoned owing to the extreme softness of the clays which were washed up in tons with the circulating fluid, covering the derrick floor.

Fig. 7 shows the relative speeds of a few wells sunk alongside percussion-drilled wells, and the table below gives a very rough approximation of the relative costs of a 3000 ft. well drilled by the two systems. Fig. 8 shows the average drilling speed for percussion and rotary in a 3000 ft. well. Obviously local circumstances are far too varied to give more than a mere approximation of the relative costs.

ROUGH COMPARISON OF SYSTEMS (3000 ft. well).

	Californian cable.	Rotary.
Cost of complete plant	$30,000 ..	$35,000
Cost labour day (8 hr. shifts)	$65 ..	$90
Oil fuel per day	10 bls.	35 bls.
Fuel costs per day at $1 per bl... ..	$10 ..	$35
Water costs per day	$10 ..	$25
Consumable stores per day	$20 ..	$20
Total running costs per day	$105 ..	$170
Average speed per day .. .. say	20 ft. ..	50 ft.
Average time for well	150 days	60 days
Average cost per foot	$8 ..	$3.12
Approximate casing used	200 tons	78 tons
Approximate cost casing used at $120 ton	$24,000 ..	$9,360
Total cost 3000 ft. well excluding transport and overhead charges .. say	$40,000 ..	$20,000

The above figures are exclusive of transport and overhead charges, which vary too much to give a generalised sum. Speeds and costs fluctuate between very wide extremes. Thus in the indurated Tertiary beds of Peru average speeds of 50 to 60 ft. daily in 2500 ft. wells are usual, and costs of $3 per feet customary; on the other hand, speeds in the unconsolidated Tertiary beds of Burmah do not average more than 6 to 7 ft. a day in 2500 ft. wells, and the cost per foot may exceed $12. Both by percussion methods. The same extremes are to be found in rotary drilling, where in one field rates of 100 to 200 ft. daily may be maintained, whilst in others the average rate may not exceed 20 ft. daily.

A much advertised well in California was drilled by rotary to a depth of 3520 ft. in under 15 days, including the setting of two

columns of casing. The deep rotary-drilled wells of the Californian Los Angeles basin wells cost between $20 and $25 per foot.

The rotary flush drill is having a revolutionary and even disturbing influence on the oil industry generally. By its means deep wells can be quickly sunk in newly discovered fields, the penetration and isolation of upper gas-bearing or low-producing oil sands being accomplished without much difficulty, delay or expense. By its means the rich Tertiary fields, of the unconsolidated type of strata which yields so freely, can be rapidly developed, with the result that within the course of a year or two outputs of 200,000 to 300,000 bls. a day can be reached, throwing on an unprepared market a glut of oil which not only depresses prices but introduces problems of extreme difficulty to arrange for its collection, storage and disposal. No less difficult is the problem of handling the enormous quantities of gas suddenly rendered available. Where land is cut up into small plots wasteful development is an unavoidable consequence, and American operators are again seeking to initiate a policy of pooling the output of circumscribed areas of fields, thus permitting rational and scientific spacing of wells, and so adequate utilisation of gas, the natural propellant of oil.

The Evolution of Oil-Well Drilling Methods.

By Mr. A. Beeby Thompson.

Mr. Beeby Thompson, in introducing his paper, said he submitted it as an endeavour to indicate briefly the evolutionary progress of drilling during the last twenty-five years. Only those who had been connected with oilfield development during that period could adequately appreciate the alternate hopes and disappointments which had met repeated but premature introductions of new methods. Doubtless the development of drilling methods was not unlike the development of other branches of engineering, such as, for example, the internal-combustion engine and electric power, but in the case of drilling the personal factor came perhaps more into play than in any other branch of industry. Each well was under the sole control of a single senior operator, usually untrained in any other trade, and his individual judgment had to be exercised almost every hour of the day. A single injudicious action in dozens of different ways might lead to the loss of the tools, followed perhaps by months of costly and tedious fishing operations. It was not, however, often a mere monetary loss, for delay in reaching oil-sand, actively and aggressively developed by competitors, might lead to a serious loss of oil through failure to participate in the flush production.

It was perhaps only natural that drillers who had acquired considerable skill on one particular type of rig should resent the introduction of a new process which they might honestly view with scepticism, for drillers' views were in reality very parochial. Without doubt that antipathy to new methods had delayed progress. On the other hand, designers and manufacturers were not free from blame, for just as the practical driller resisted innovations, so the designer failed to accommodate his designs to incorporate essentials they could never appreciate. That conflict of views was especially seen in the efforts to introduce electricity and the internal-combustion engine for drilling. To-day there was constant antagonism between the wire-rope manufacturers and the operators who would continue to coil their high-tensile steel cables on small diameter drums. Manufacturers of plant and material were embarrassed by demands from operators for goods that would resist extremes of torsion, tension, abrasion, flexibility and hardness, and it must be admitted that considerable credit was due to the engineers who could produce material which the average driller could not break. The punishment administered to ordinary drilling machinery and tools was indeed remarkable, and, as an engineer, he marvelled at the resistance of the metal to abuses which were perhaps never given to other types of plant. However, quite apart from the plant and its use or abuse was the psychological element. Only those with imagination could become good drillers, as they alone could properly visualise what was proceeding beneath the ground, whether drilling or fishing. To picture of the behaviour of tools at the end of a 3000 to 5000 ft. flexible cable, or the action of a bit at the base of a similar length of piping, required a vivid imagination when working in changing types of strata. The successful driller was gifted with infinite patience. He took no risks, and pulled out if the tools were not running smoothly. The less cautious endeavoured to secure by brute force what could not be achieved by caution, and were, in consequence, constantly in trouble with some broken machinery or fishing operation. Quite apart, however, from skill, the rate of progress and success of drilling depended often upon the personal integrity and character of the operator. Unless induced by some contingent benefit, well-drilling favoured in an exceptional degree those disinclined to put in an honest day's work, and the regrettable, yet undoubted and Union-supported, disposition of labour to curtail output, notwithstanding reduced hours and higher pay, forced oilfield operators to consider means of combating that disposition. At times footage had been deliberately restricted to a certain daily amount considered to represent a fair day's output. Contract drilling had long been practised in oilfields, but there were so many obvious occasions when that was difficult or impossible

that other means had been sought to impart that interest which day-work pay failed to stimulate. Various methods had been tried, such as bonuses on completion of wells to oil or to a certain depth, footage premium, and in some cases participation in the output of the well. Sometimes the wells were drilled with the principals' tools and materials at a fixed rate per foot, with provision for daily payment that just covered expenditure during delays enforced by the directions of the principals, such as cementations, testing for production, etc. That such interest did materially influence speed had been repeatedly demonstrated. Such increase might not necessarily be due to improved drilling rate, but rather to a diminution of those delays which arose from lack of foresight, and which were regarded by so many drillers as outside their province. It was surprising how much time was lost at wells unless kept under the closest supervision. Waiting for tools, casing, fuel, water, stores, repairs to tools, all of which might have been prevented by intelligent anticipation, often reached an important proportion of the time taken on the well. Several cases could be recalled illustrating the value of an incentive. In one case wells were being drilled by rotary to 1500 ft. in about six months. On introducing contract drilling, almost in desperation, wells were sunk to the same depth in 15 to 30 days. In another case rotary drillers were offered and earned a bonus of £100 if they completed a well to 2000 ft. in 30 days. A previous well by percussion had taken eight months to reach the same depth. In both cases the wells were too far removed from the administrative centre to secure constant supervision, and the tropical climatical conditions were such as to discourage activity. Certainly the change did not afford the management any relief of work, for the tables were at once turned, and it was the staff who became pestered without respite night and day by impatient angry drillers, who would listen to no excuse for a moment's delay in the delivery of any article. There were then no stoppages for tools, boiler water, light or fuel, and any native workman who did not pull his weight was quickly thrown out of the rig. No stoppage of the rig for meals was then entertained, and no eight-hour shifts were then discussed ; indeed, the drillers could scarcely be induced to leave the rig. Spirit was put into the work, with the astounding results described. The question of working hours was one upon which varied views were held. Twelve-hour "tours" were usual until recent years, and the high pay of drillers compared with other craftsmen was undoubtedly influenced by the longer hours worked. It was now claimed that the more arduous work connected with deeper drilling, especially rotary, called for a reduction of working hours. An increased number of tours spread responsibility and made it more difficult to procure parties which worked in harmony.

Whatever the views expressed during day-work, it was noticed that on contract work drillers preferred twelve-hour tours when removed from Union influences and intimidation. As a rule drillers working in remote districts, where healthy distractions were few or absent, did not hanker after longer hours of freedom, and in the writer's experience such longer rest led to abuses which were a hindrance to the work. The driller question had rather been belaboured, as it was felt that drilling progress depended as much on the operator as on the plant. It was essential for rapid progress that means should be found to conciliate and adequately reward the driller, without whose hearty co-operation drilling speeds would not advance as they should. Well-drilling was essentially an operation where individual skill told, and the best American drillers were so well known and appreciated in their own country that they could rarely be induced to go abroad. Elsewhere dependence must usually be placed on less skilled and less dependable craftsmen, whose control was often difficult. On account of the free interchange of technical literature, and the internationalisation of the oil industry, drilling tools and methods were assuming more in common, and operators of many nationalities and races were acquiring a knowledge of American systems. As there were annually drilled about 20,000 to 30,000 wells and 40,000,000 to 60,000,000 ft. in the U.S.A., that country must necessarily lead in the manufacture of drilling machinery and casing. Until recently there was little disposition to standardize drilling tools and plant, with the possible exception of casing. In consequence, there was much waste of plant and tools necessitated by modifications of plant. Committees were now at work in America on standardization, and its general acceptance would lead to considerable economies in plant and save many inconveniences and annoyances in spares. Notwithstanding criticism, there appeared to be little doubt about the rotary replacing other drilling methods in many fields. From the Gulf Coast fields its use extended to California, where it was further developed and spread into the Mid-Continental field. In a number of the Mid-Continental fields the rotary was successfully competing with percussion rigs, notwithstanding the presence of hard sandstones and limestones that had to be pierced. By the judicious use of fish-tail, disc and roller bits the various hard bands were being negotiated, and wells were being completed in quicker time, with less casing, and at lower cost than the old method. It was unlikely that the rotary would replace percussion cable methods where compact strata, interbedded with hard bands of sandstone, permitted rapid progress to great depths in open holes with little fluid, but where heavily caving ground necessitated high fluid levels and many strings of casing to support the walls, it was sure to find an eventual home. Just as the criticism against

the rotary had been exaggerated by opposers of the system, so had the advantages often been magnified by its supporters. The writer's experience in many fields showed that in the majority of cases it was some time before the local peculiarities were fully appreciated and the difficulties mastered. Two of the most commonly raised objections were the obliteration of samples and the concealment of oil or gas. Both objections applied with nearly equal force to deep percussion drilling as now practised, where it was usual to work with a heavy column of fluid to reduce caving tendencies and ensure freedom of long casing strings. The tendency of the rotary to produce crooked rather than deflected holes was generally admitted and thought to be due to the wobbling of the bit on an irregular or inclined surface of hard material. Holes were frequently reamed with a flat or star bit, usually the former, and if guided by a length or two of pipe equal to the size of casing it was intended to insert, no difficulties were usually encountered. Twist-offs were probably largely due to forcing progress in a deflected hole or to excessive feed. If the automatic control arrangements now being tested could be perfected, many of the twist-offs would be avoided, as the feed would be automatically adjusted by the weight of the drill-pipe and so the pressure on the bit.

The Chairman said the best thanks of the Section were due to Mr. Beeby Thompson, because he had really put forward two papers, the one which he had read that afternoon being, with the exception of the last paragraph, entirely supplementary to that which had been printed. The paper drew attention to some very interesting features in connection with the difficult problems of drilling for oil, and he had no doubt would lead to a very interesting discussion. Mr. Thompson had referred to the question of standardization, which was a matter that had been for some time past, and still was, receiving very serious consideration in America, where influential committees of experts to deal with various phases had been appointed, and in some cases had already completed their investigations and submitted their reports. Such work as that, started as long as 60 years after the first drilling of oil wells, was certainly belated, but none the less welcome for being brought forward now. The whole industry could not but benefit materially from such investigations, because it would be possible to standardize on certain items and material which would conduce to the greater certainty of drilling wells and undoubtedly to more economical methods of doing so. It was not very long ago that the deepest well in the world was drilled in West Virginia by the cable tool method. The method really reached its limit of capacity because the rope was the chief source of trouble. Various types

of ropes were tried, spliced ropes of various diameters, and every possible means adopted, but in that case it was the rope which was the limiting factor in determining the depth to which the well could be drilled with present-day plant. The author had referred in his paper to Galicia and had stated that the old Canadian pole-tool system was still persisted in for deep wells. That was the case until within the last few months, but the standard cable tools had now been introduced and had made very satisfactory progress. One point he wished to mention in connection with the rotary, namely, the utility of that system to the geologist in that it gave an opportunity of producing cores which were of such great value to him. The question of cores was now being very seriously gone into, as it never was before for oil-well drilling. There was one other point, an automatic method of regulating the weight on the bit. Means were now being tried out and probably definite conclusions would be reached within the next two or three months by which the load on the bit and the speed of drilling was automatically controlled electrically.

Mr. F. G. Rappoport said there were many points in this interesting paper that called for discussion. He would only deal with one, the question of materials of construction used in oil-well drilling. The author of the paper had shown very clearly what had been accomplished during twenty years by way of improving tools and appliances. Twenty years ago 5000 ft. would probably have been regarded as an inaccessible depth. It was interesting to speculate as to what depths were going to be attained during, say, the next twenty years. As oil is found in the strata of all geological ages, there is no doubt that much oil lies hidden at what are to-day inaccessible depths. One foresaw depths of 10,000 to 12,000 ft. already. Drilling machinery and tools had increased vastly, but the weak point in all drilling methods was the mode of suspension of the tools, whether by pole, cable or drill-pipe. It was all a question of strength of material, and it was an easy mechanical problem to work out. On the one side of the equation we have the total load, ever tending to increase with greater depth drilled, and a measure of which was the horse-power of the engine or the motor; on the other side were the strength of the material and the modulus of the section employed. As regards the strength of material employed, one was limited to-day, in all probability, to a tensile stress of 40 tons to the square inch. Wire rope might withstand a higher stress, but the want of homogenity of the wire rope structure rather offset the advantage in the strength of the individual wires. If one commenced altering the modulus—*i.e.*, increasing the size of rods, cables and tubes, and with this the diameter of the well and casing, one was going to come up imme-

diately against the very objection of increased drilling costs, which the author raised in the early part of the paper. Such increased drilling costs might raise the price of oil produced from great depths to an uneconomical degree. We thus calculate that the pole will have reached the limit of its safe use at 3000 ft., the steel cable of present section at about 7000 ft., and the drill-pipe of present section at probably 8000 ft. We are thus approaching the limiting depth of present-day scantling. Eliminating, therefore, for this reason, any idea of increasing the weight of the appliances in use, one was thrown back upon the necessity of improving the materials used in construction. One could hardly expect to drill to the great depths one now foresaw without doing so, unless one cut dangerously into one's factor of safety, which, in oil-field work, had to be an ample one. One doubted whether the present tensile stress of steel used with the factor of safety indicated was sufficient with present scantlings of cables and tubes to reach depths of 10,000 ft., or more, that it might be necessary to drill to in the future.

Increased research on the subject of material was therefore clearly indicated. It is of interest to know—and most of the members were, no doubt, aware of it—that to-day seven of the leading learned and technical Societies, of which the Institution of Mining and Metallurgy was one, were investigating this very question from a practical point of view, and that an Inquiry Committee was now working on the alloys of iron. The speaker had heard Sir John Dewrance (then President of the Institution of Mechanical Engineers) say, when mentioning the work of this Committee, that if it were only possible to get another 100 tons per square inch and also another 100° C. the whole world would benefit greatly. The benefit to the oil industry, and so to the world also, by the possession of such a material was obvious. We would not ask even for another 100 tons per square inch; if it were possible to get only another 35 tons per square inch it would make all the difference.

Mr. A. E. Kitson said that it had given him much pleasure to hear the author advocating the rotary method of drilling. In his opinion that ought to have been more generally adopted many years ago. Had that been done the investing public would have been saved many thousands of pounds in useless boring. The mechanical difficulties originally advanced against it had long been overcome, with the result that now we were able to note with certainty the characters, positions and ages of the various beds forming series of fossiliferous strata in bores.

Two examples from his own experience might be mentioned where the use of percussion instead of rotary drills had resulted in

much loss. In one case between 2000 and 3000 ft. of useless boring had been done in old metamorphic rocks, consisting mainly of mica-schist. Examined by one untrained in mineralogy the material obtained looked like a fine micaceous sand of detrital origin, but it was really comminuted mica-schist. Though such rocks in certain parts of the world did occasionally contain oil, that oil was not present in profitable quantities. In other districts by drilling with the percussion method through easily pierced strata the material obtained showed a mixture of Pleistocene, Pliocene, Eocene and Cretaceous fossils, most of which were so much broken by the drill as to be unidentifiable. Had the material been obtained by core-getting drills the evidence would have been of great value at the present time. He mentioned this to stress the necessity for getting as good and clean a sample as was possible of the material in the bore.

He had in mind a very useful type of drill, the Calyx drill, which furnished a good core. It had been in use in the State of Victoria during the past 30 years.

The bits were made of special steel, and cut easily through the common kinds of sedimentary rocks. When the teeth became worn they were repointed on the spot. One advantage of this drill was that when a very hard stratum, such as quartzite, or a dyke of igneous rock, was encountered the rods were simply raised, the Calyx bit taken off, and replaced by a diamond bit, which cut through the hard rock. Thus, with the occasional use of the diamond bit, all rocks met with were easily cut.

He was rather surpised that in Europe the Calyx drill had not been much used, so far as he knew, or could learn, after various inquiries in England.

Referring to the important point mentioned by the last speaker, regarding the metal for bits for very deep boring, he thought that among the serviceable alloys of steel with various metals one or more would be found suitable for that purpose.

Mr. C. Z. Bunning asked the author if he had any experience of the Fauck drill.

Mr. Alfred W. Nash said that arising out of the last speaker's statement he thought a little fuller description might have been given in regard to the Fauck Express Inverted Flush method of drilling. He saw that system being used last year, and was particularly struck with the clean samples of formation which were brought to the surface.

It was not a continuous core, but with the help of the drilling log and the samples obtained the information available was, he thought, equal to that obtained by the core drill which had been just previously described.

In any case it would not be fair to condemn the system, or, in fact, any system, until it had been tried side by side with others under the same conditions, and this had been done in very few cases.

Until all the systems of drilling were tried side by side, in different formations, under the same conditions, the controversy as to the merits of various drilling systems would go on for all time.

The author had dealt with the subject very fully considering the length of the paper, but there was one statement which he thought was just a little misleading. It was in regard to the pole tools, which, it was said, were used where alternations of hard and soft steeply dipping strata called for underreaming and maintenance of shoe close to the bit owing to caving and to maintain a straight hole. He quite agreed it was possible to keep the casing close to the shoe when using an eccentric bit, but he should have thought it would have been more correct to have said that the Canadian system of drilling was introduced into many fields, especially those in Europe, by Canadians without any regard to the formation to be drilled through, because they were experienced in no other system.

In his opinion the Canadian-Galician system of drilling, using rods, had many advantages over the cable system when semi-skilled labour was used, as such method was more positive and it required less skill.

Where steeply inclined strata occurred he was doubtful whether there was any advantage over the ordinary cable method, as the danger of a crooked hole was practically as great with the one as with the other. Under such conditions, unless a hole were drilled with tight rods the bit was just as likely to go off the true, and tight-rod drilling required almost as much skill as tight-line drilling by the cable method.

The danger of drilling a flat hole was always present when using eccentric bits, and as a result of inquiries made in Poland last year in this connection, he came to the conclusion that there was not a sufficient width of cutting metal on the wing. He would like to ask the author whether he agreed that the present bits were not heavy enough, and that with a greater width of metal on the outer wing it would be possible to overcome the difficulty of the flat hole.

With the remarks of the author on manilla cable drilling he quite agreed, but he thought a warning should be given in this connection so far as British oil companies were concerned. Although manilla cable drilling was the fastest percussion method, unless it were in the hands of experienced drillers it would undoubtedly prove the slowest and would certainly lead to a crooked hole.

To learn to drill satisfactorily with a manilla cable took years of experience, and when it was borne in mind that the best American

drillers did not leave America, he would advise British oil companies to stick to the wire line and leave the cable alone.

With regard to the rotary mud flush system, undoubtedly it was the fastest drilling method for use in a soft or medium hard formation; at depth it was also the cheapest in such strata, despite the high daily cost.

Where a core barrel was used, much more accurate information as to the formation being passed through could be obtained than with the percussion method. High water and gas pressures could also be controlled, and what was still more important, heaving sands, which often meant the loss of the well altogether when using the percussion method, could be passed successfully.

He was afraid he could not agree with the author that there was a greater tendency to drill a crooked hole with the rotary than with other systems. On the contrary, provided the weight of the stem was kept off the bit, it was his opinion there was less danger.

A distinct advantage in favour of the rotary was that fishing jobs were comparatively few and easier to get over as compared with other methods, although there was more danger of losing the hole if the fishing job became too difficult and complicated.

In his experience one great advantage of the rotary was that men could learn rotary drilling quicker than they could learn cable drilling, and he had found that men who had had no experience of drilling at all seemed to take to the rotary method far better than the old cable drillers.

Mention had been made in the paper about extremely hard rock being drilled through easily, and he had in mind a case he had seen last year.

In July last he saw two wells spudded in, next door to each other, one a cable rig with wire line, the other a rotary rig. The formation at this particular spot, due to an overthrust, had about 1200 ft. of extremely hard rock to be drilled through before the softer formation was reached.

At the beginning of last April the cable rig had reached a depth of 800 ft., whereas the rotary was only down 350 ft. and the cost of new rollers for the roller bits represented a small fortune.

In both cases the machinery suppliers had supplied the crews, and as it was the first experiment of this kind in that particular field there was no doubt that the rotary was being run under the best conditions possible.

The danger of going through oil-sands, especially those which had had the cream of the production taken off, was easier than suppliers would allow.

Another case he had in mind was where a rotary hole was drilled into an oil-sand and the driller was not aware of the fact

until the production foreman from the next plot came over to inform him that instead of pumping oil out of his well he was pumping drilling mud.

That showed that there was still a danger, in spite of the claims made by suppliers, of mudding up oil-sands.

The views expressed by the protesting foreman with regard to the possibilities of passing oil-sands with the rotary would have made a very interesting contribution to the discussion.

Mr. A. Beeby Thompson, in reply, said that Mr. Rappoport had raised a very important issue. It was not only in drilling that the particular difficulties he referred to concerning material were found, but in every branch of engineering. The reason why rotaries had not been introduced sooner was on account of the failure of materials to withstand the duties demanded. He had used some of the early rotary rigs, but owing to the incessant troubles experienced and the frequent breakages he had almost been led to believe that it would fail. But by improving the material and strengthening up every part of the rig it was possible to perform now what then seemed unattainable. The question of material was receiving the increased attention of engineers every day, and there was no doubt that very great improvements would be witnessed in the next few years. With regard to Mr. Kitson's remarks, the Calyx was a drill which had given very great satisfaction in Australia and was subsequently introduced into England, where it was employed with a large measure of success. It was quite a good rig for general purposes, but it was not designed to deal with oil-field work. The Calyx was one of the earliest of rotary drills, and one of the best rigs of its day. The cores it cut were quite satisfactory, and it created some sensation when first introduced. The rotary had its limitations. Where it was necessary to obtain accurate geological information, as in mineral mining, core drilling was essential, but when drilling for oil there might be several thousand feet of uninteresting beds to pass before entering the oil measures, and there was little value in accurately sampling this material. Most of the great oilfields were drilled up before any question of coring was raised, yet with the aid of a geologist good logs could be produced. With regard to the Fauck drill, it was an excellent plant, doing very good work on the Continent, but he was afraid it was doomed. Quite recently he had been studying the relative merits of different drills in Rumania, and the data he collected showed that they did no better work than the percussion drill or the rotary. In 1924 no particular rig could be singled out, and it was perhaps premature to say which type would ultimately be generally adopted. He, however, thought the rotary would eventually cut all the others out when the local labour became

accustomed to the method. At the moment the Fauck was very largely and successfully used. Undoubtedly rods used as they were were not satisfactory; the vibration and shock on the rigs was very severe. He felt convinced that the more silent and scientific method of abrasion would gradually replace percussion methods. Mr. Nash had raised a number of important points. He agreed that there was a great deal in the design of eccentric bits. Eccentric bits varied very much in design, and the drillers who understood them dressed their bits to suit particular strata. Doubtless there would often be an advantage in widening the wings. He could not himself understand why eccentric bits were unpopular in many other countries. In America they had never been used to any extent. There was no reason why they should not be successful, as they had performed excellent work in Rumania. With regard to crooked holes and rotary drilling, he always considered that much of the trouble was due to the fact that a fish-tail bit was used, which was merely a flat strip of metal that could wobble about a very great deal. If a circular cutter was attached to a few lengths of casing it was often possible to ream out a hole which would freely admit the casing column. In one case many weeks were occupied in an endeavour to insert a column of casing when, despite the protestations of the drillers, he felt sure it was simply due to obstructions and irregularities of the hole. A fish-tail bit was attached to several joints of casing and the hole reamed to bottom, after which the column of casing was lowered without the slightest trouble. It was a well-known fact that mud used for circulation would travel from one well to another. In the case mentioned in the paper the sands were hard and would not themselves admit the mud very far into their body, and he had expressed the view that it should be possible to pass partially exhausted sands without very much difficulty, but apparently the strata was badly fissured and the fissures had probably been opened by gas, thus permitting the mud to travel towards other wells from which fluid was being extracted.

In Burmah, where the operators were anxious to tap the deeper sources, they might be forced to pass through the upper parts with percussion tools, and cement them off, and then proceed with the rotary when there was no further danger.

The Chairman, proposed a vote of thanks to Mr. Beeby Thompson, which was carried unanimously.

Petroleum Engineering.

By C. Dalley, M.Inst.P.T.

The petroleum industry calls for the employment of every branch of engineering, and as it is impossible in the scope of this paper to attempt to deal comprehensively with the whole, it is proposed to concentrate on certain items which are representative of the progressive application of engineering, more particularly in connection with refineries.

Storage Tanks.

The principal development of progress in the design of storage tanks has been the increase in the ratio of tons of oil stored per ton of steel, still retaining an accepted factor of safety. In the larger sizes particularly there is a definite economic depth for any given diameter which tends to standardise dimensions. Figure 1 shows various sizes thus standardised.

Larger tanks exist of 12,000 and 15,000 tons capacity, and designs have been prepared for a tank of 50,000 tons capacity, but for obvious reasons it is not probable that sizes greater than, say, 15,000 tons will be commonly used.

Figure 2, together with the specification apended, shows in detail the 10,000-ton tank, which is 116 ft. in diameter and 40 ft. in depth. The number of tanks of this design now in commission approaches 200. This tank, whilst having a factor of safety equivalent to accepted British practice, has a deadweight of less than 250 tons.

In order to maintain the factor of safety of the vertical joints without increasing the weight of the side plates, the three lower strakes have double butt joints instead of lap joints.

The bottom plates are $\frac{1}{4}$ in. thick with a peripheral ring of sketch plates of $\frac{3}{8}$ in. thickness. It will be noted that lowering holes are provided, in order to facilitate erection.

Diameter. ft.	Diameter. in.	Height. ft.	Height. in.	Capacity. Tons of Oil nominal.	Capacity. Tons of Water actual.	Capacity. Gallons nominal.	Capacity. Gallons actual.	Load on Foundations. Tons per sq. in.	Total Weight of Tank (tons) Empty.	Weight of Tank per ton of Oil Capacity.
116	0	40	0	10,000	11,795	2,600,000	2,633,670	1·0	242·0	0·023
116	0	30	0	7,500	8,845	2,000,000	1,975,220	0·75	192·0	0·0243
82	6	40	0	5,000	5,966	1,250,000	1,332,130	1·0	139·0	0·026
82	6	30	0	4,000	4,475	1,000,000	999,100	0·75	110·5	0·0276
65	0	40	0	3,000	3,703	800,000	827,170	1·0	—	—
65	0	30	0	2,500	2,778	600,000	620,190	0·75	—	—
50	0	40	0	2,000	2,191	500,000	489,300	1·0	55·3	0·0282
40	0	35	0	1,000	1,227	275,000	274,000	0·825	35·1	0·032
40	0	30	0	900	1,062	225,000	234,870	0·75	32·1	0·034
30	0	30	0	500	592	125,000	132,080	0·75	—	—
30	0	25	0	400	493	100,000	110,080	0·625	—	—
25	0	25	0	300	342·5	75,000	76,440	0·625	14·7	0·048
25	0	20	0	250	274	60,000	61,180	0·5	12·8	0·052
25	0	15	0	200	205·5	45,000	46,000	0·375	—	—
20	0	20	0	150	175·5	40,000	39,120	0·5	—	—
20	0	15	0	100	131·5	30,000	29,340	0·375	—	—
15	0	15	0	65	74	15,000	16,510	0·375	5·7	0·0865
15	0	10	0	40	49·5	10,000	11,030	0·25	4·55	0·103
10	0	10	0	20	22	5,000	4,890	0·25	2·5	0·131

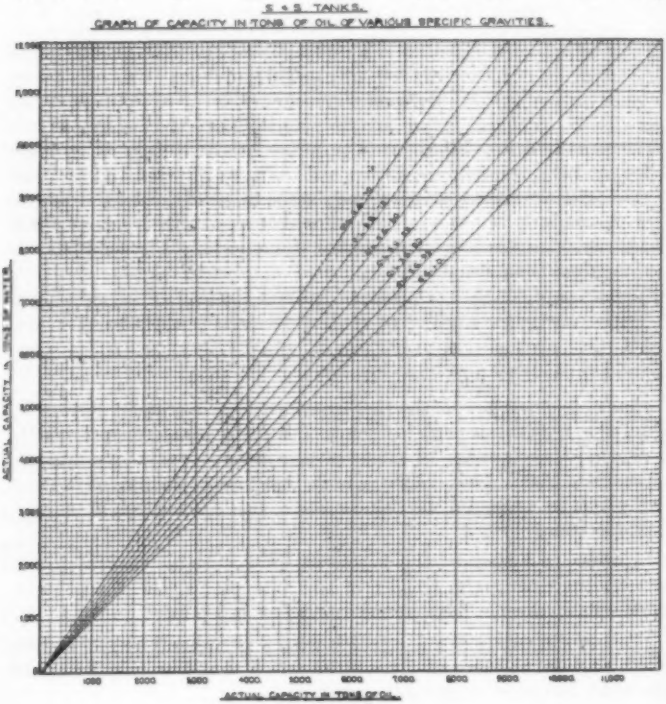

S. & S. TANKS.
GRAPH OF CAPACITY IN TONS OF OIL OF VARIOUS SPECIFIC GRAVITIES.
ACTUAL CAPACITY IN TONS OF WATER.
ACTUAL CAPACITY IN TONS OF OIL.

FIG. 1.

With regard to the roof, this tank is intended as standard, not only for the various grades of oil, but also for all conditions of foundations, and as certain foundations preclude the use of central supports or king posts, the weight of the roof is borne on the walls of the tank only.

Closer attention is being paid to the rendering gas-tight of tank roofs, in order to eliminate losses by evaporation as far as practicable, and the roof plates are either rivetted at close pitch, as in gas-holder practice, or tacked together and welded in position, where facilities exist for such work. The tank having been rendered absolutely gas-tight, it is essential that some effective relief valve be fitted.

The use of valves which are spring controlled in such positions is unsatisfactory, due to corrosion affecting the springs and rendering the valves inoperative, and further a vacuum valve cannot be adjusted with sufficient accuracy by ordinary spiral spring adjustment.

Fig. 3 shows a simple type pressure and vacuum valve, which is found to be positive in action, both on pressure and vacuum, and is capable of accurate adjustment. Although actual figures are not yet available, the adjustment of the pressure valve to give a pressure of 5 lb. per square *foot* has had a marked effect in reducing evaporation losses. The drawing referred to is explanatory.

It will be noted that a nickel gauze screen is provided, so that adjustment or inspection of the valves can be readily made in safety by the removal of the hood. This fitting on oil fuel tanks (or other heavy oil) can have the valve plates and discs removed. The fitting then becomes a simple ventilator at no greater cost.

Lightning protection is provided by the elongation of every sixth handrail stanchion, which, in addition to an effective earth connection on the tank, is considered adequate protection.

All fittings, such as stools, are of cast steel.

It is considered an advantage to have a separate inlet and outlet. On the inside of the tank, on the inlet side, an ordinary flap valve is fitted (Figure No. 4), so that in the event of any breakage external to the tank, this flap valve would function and eliminate, or greatly reduce, the leakage of oil.

It has been a common practice in the past on the draw-off connection of the tank to have a swivel swing pipe of considerable length, which in the case of a tank 30 or 40 ft. in depth is unwieldy, with the result that it is fixed in one position and seldom, if ever, operated.

The modification shown in Figure 5 fulfils, it is suggested, all the requirements of the old swivel pipe. It is capable of very easy and simple adjustment; in addition, it will be noted that the swivel pipe in its lowest position rests on a seat, and thus acts as a

preventative of leakage should any external valves or connections fail in operation.

The difficulty of maintaining gas-tight the gland through which the swivel pipe supporting rope passes is also eliminated.

Pipe-Line Pumping Plant.

In those countries where the transport of heavy machinery is a very difficult and costly operation, the smaller weights and size of pumping plant, rendered possible by the use of centrifugal pumps, has resulted in their increased use. This has been further augmented by the development in the last few years in the reliability, flexibility and efficiency of this type of pump.

Figure No. 6 shows an outline, including general dimensions, of a pipe-line pumping unit consisting of a high lift centrifugal pump direct coupled to a steam turbine. The pump duty is 1350 gallons per minute, against a total head of 600 lb. per square inch, dealing with crude oil of specific gravity 0·85.

The turbine develops 800 h.p. as normal full load, but is capable of overloads up to 1000 h.p. at 2000 r.p.m.

In a pipe-line composite of 10-in. and 8-in. pipes, and approximately 150 miles long, the terminal and three boosting stations at roughly 40 miles intervals are equipped with these units.

The static head, due to the contour of the country and also the distance between stations, varies; but the pumps at all four stations *operate in series*, any adjustment due to head or distance being made by speed variation of the respective units.

This is an excellent example of flexibility, and the installation is, it is believed, unique, not only in connection with the transport of oil, but of any other liquid.

A brief description of the units comprising one of these pumping stations may be of interest, particularly with regard to the safety precautions observed.

The steam plant consists of four water-tube boilers, which are oil-fired on the pressure system, and generate superheated steam at 180 lb. pressure and 200 degrees superheat to the turbines, direct coupled to the pumping units. The main pumping units are in duplicate.

For the provision of electric light and power (the latter being used for operating the turbine auxiliaries) small generating sets are included.

Cooling ponds in connection with the condensers are interposed between the pumphouse and the boiler house.

The furnace fronts of the boilers are enclosed with a framing covered with wire gauze. This is intended as a preventative against the possibility of oil leaking from pipe lines being drawn in and ignited at the burners and flashing back.

In connection with the pumphouse and in addition to the provision of large CO_2 extinguishers, a valve is arranged so that it can be operated from outside the pumphouse, which automatically cuts the steam supply off the turbine and floods the house with steam.

An alternative arrangement, utilising steam sprinklers, is also mentioned as being of some interest. It is obviously impracticable to have steam in the sprinkler piping. The piping and a small tank connected thereto is filled with water; when the sprinkler functions, the water discharges through the sprinkler in the usual way; and when the small tank is empty, a ball float valve attachment switches steam into the sprinkler piping.

These stations have been in commission over three years, and the original claims of reliability and continuity of operation have been fully justified.

Refinery Requirements.

In addition to the specific requirements of a refinery, the general services which have to be supplied are water, drainage, steam and electricity. Of these it is proposed to give greater attention to the two latter.

Water.—In cases where refineries are conveniently situated alongside large rivers, or on the seaboard, the question of water supply for condensing purposes presents no great difficulty. In other cases a reservoir is necessary, and is generally of such a capacity that artificial cooling is not required.

Drainage.—It is generally necessary to include in the drainage system some method of separation for recovery of spilt oil, and the neutralising or recovery of chemicals.

Steam and Electricity.—Steam and electricity are coupled together for reasons which are given later. The steam requirements of a refinery generally call for quantities of steam at various points, sometimes rather widely distributed. The overall economy of a central battery of boilers over individual batteries cannot, however, be questioned, and with efficient lagging the losses in the distributing pipes from a central battery are quite small. It may be taken for granted, therefore, that a modern refinery would be equipped with a central steam generating battery.

Electricity may be generated by coupling electrical machines to either oil engines, steam engines, or steam turbines.

The general refinery requirements of low pressure steam, combined with a supply of electrical energy, are very similar to those of paper mills and dye works, and, as in these cases, the use of reducing or back pressure steam turbines becomes an economic proposition.

High-pressure superheated steam is generated in a central boiler plant; the steam is supplied to turbines direct coupled to electric

generators. The energy in the steam entering the turbine at high pressure and exhausted at, say, 30 or 40 lb. pressure, is converted into electricity, and the low pressure steam passes out for distribution in the refinery. If the quantities of electricity and steam were fixed, it would be possible, as in the case of some works, to utilise pure back pressure turbines, and eliminate condensing plant.

The conditions in an oil refinery call, however, for greater flexibility, and the turbines are equipped with condensers, not necessarily of the full capacity of the turbine.

A reducing valve is also fitted between the high and low-pressure steam mains. The supply of steam and electricity now becomes automatic. If a greater amount of electrical energy is required than can be produced by the low-pressure steam demand, then additional steam passes on into the condenser in the ordinary way. If the requirements of low-pressure steam exceed that produced by the equivalent amount of electrical energy, and the pressure in the low-pressure main falls below a predetermined figure, then the additional requirements of low-pressure steam pass through the reducing valve from the high-pressure main. After some experience of the actual conditions ruling in the refinery, these adjustments are naturally reduced to a minimum.

The principle and the economies are now well known, but it is believed that it is only recently that it has been applied to oil refineries.

The general particulars of an existing plant working on these lines are as follows :—

The boiler house plant consists of six water-tube boilers, which are arranged for consuming either solid, liquid, or gaseous fuel.

Coal handling and conveyor plant are included for burning low grade coal on mechanical stokers, and the evaporative capacity of each boiler is 25,000 lb. under these conditions.

The change to oil firing is made by withdrawing the mechanical stoker and installing pressure burners.

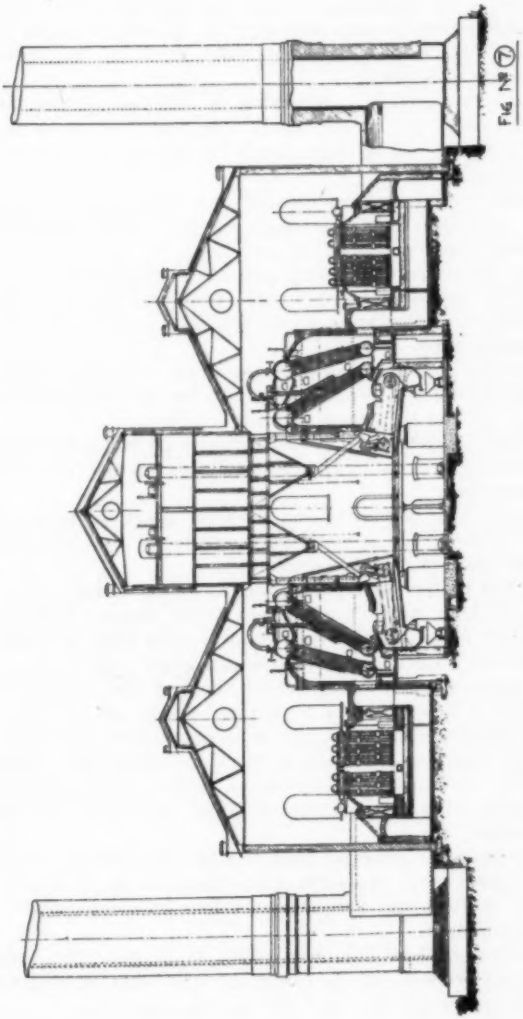
The evaporative capacity of each boiler on oil fuel is 35,000 lb. per hour. Steam is generated at 180 lb. pressure, with a superheat of 200° F.

The turbine plant consisting of three units, each of 2500 kw. capacity.

The economic, but not the maximum, draw-off steam for these units is 50,000 lb. per hour at 30 or 40 lb. pressure.

The condensers are of the "Jet" type, with rotary air pumps, and are capable in this instance of dealing with the whole of the steam for the maximum output of the alternator, functioning as a pure high-pressure turbine, and as such has the equivalent efficiency.

The general arrangement of boiler house and power house, with the high and low-pressure steam pipes, are shown in Figures 7 and 8.



With this plant, the thermal efficiency—that is, the ratio of the total B.T.U.'s passed into the boiler house to those economically utilised either as steam and/or electricity—is in the neighbourhood of 50 per cent.

Pumping.—The pumping of crude oil into the refinery, through the various processes and ultimately to refined products to stock tanks and outwards—is an important item in the engineering requirements of a refinery.

Steam and electricity, generated as detailed above, provides electrical energy at an extremely low cost, and it is therefore inevitable that it will be largely used for driving the various pumps and other units.

Centrifugal pumps direct coupled to electric motors provide an efficient and extremely economic pumping unit, particularly in capital and running costs.

Whilst the centrifugal pump still has certain limitations which may preclude its use in isolated cases, yet on account of the features mentioned, it is displacing to a very great extent pumps of the reciprocating type.

Two of the largest refineries in the world include in their equipment upwards of 800 centrifugal pumps for the pumping of oil and water, in varying sizes from 500 h.p. to 1 h.p.

Electrical Equipment.—The use of electricity being thus extended, it is necessary to consider the most suitable type of electrical plant for refinery use.

The conditions prevailing and the consequent safety precautions in an oil refinery are in many ways similar to that of a fiery coal mine, but perhaps to a less degree.

Electrical motors and controlling switch-gear have been developed to a high state of perfection under Home Office rules for satisfactory operation in fiery mines, and the experience and development gained in this sphere can appropriately be modified to suit refinery conditions. Whilst the first cost may be slightly higher, there is no dubiety regarding safety, and in the author's opinion oil-immersed switchgear throughout is an essential.

The specifications, therefore, for electrical equipment, particularly switchgear, as supplied under Home Office requirements to fiery mines, will, with suitable modifications, meet the requirements under review.

It is obviously essential that the electric lighting installation should approximate the same high standard, as weakness in this direction nullifies the precautions taken in connection with the power equipment.

In buildings where gas may collect by leakage, the wiring and fittings may conveniently be external to the building, with weather-tight fittings projecting light through the windows.

Fireless Locomotives.—It is essential to incorporate every available precaution against fire risk, and as most refineries require mechanical traction, the fireless locomotive provides a tractive agent superior to all others from the point of view of safety. The use of these has possibly been restricted in the past, due to the impression that their capacity or utility was limited. Considerable experience proves, however, this impression to be erroneous.

In the operation of a fireless locomotive the property of "regeneration" of steam is employed. The reservoir (which takes the place of the boiler in an ordinary locomotive) is charged with hot water and steam, the greater portion being water, from the central boiler battery, at a pressure of 160/180 lb. per square inch. The loco-engine is supplied with steam from this reservoir.

As steam is used the pressure falls slightly, and steam is regenerated at the lower pressure. This process continues until the pressure falls to 20/25 lb., which is sufficient to enable the locomotive to return to the central boiler battery for re-charge; a charging taking 20/25 minutes is sufficient for four hours' working.

The brakes and buffers are fitted with a sparkless compound. Water tanks are supplied instead of sand boxes, and lighting is by electricity furnished from accumulators.

These locomotives are not only "safe" in any part of a refinery, but have a further usefulness in providing a supply for steaming out tanks, etc., which are remote from a steam supply.

Distillation Plant.—The apparatus employed for fractional distillation is a characteristic and dominating feature in the ensemble of a large refinery. The increasing importance and ever-growing demand for all the refined products of mineral oil, the scale on which companies in the first rank of the petroleum industry now operate, and the particular and peculiar technical problems involved all lead here in the direction of highly specialised apparatus for primary distillation and re-distillation.

A few years ago a typical unit of distillation plant comprised about six simple cylindrical stills, some 20 ft. in length by 6 or 7 ft, in diameter, mounted over the crudest form of furnace setting. with a battery of small condensers formed of steel tanks containing coils of cast-iron rainwater piping.

To-day a modern unit of the same order may consist of twenty stills, 40 ft. in length and 12 ft. or more in diameter, with a rather impressive array of complementary plant in the shape of generators, dephlegmators, analysers, condensers, coolers, etc., mounted within a steel framework extending 60 ft. above ground level. Probably more than 1000 valves will be included, with an extensive but ordered system of piping linking the whole together. There will be a substantial building to which all the products of distillation are first conducted and then diverted to large receivers, and

another building housing some twenty or thirty electrically driven pumps necessary for the operation of the unit.

Apparatus of this kind is an essay in heat exchange on a large scale, and on the broadest basis of classification may be grouped with steam generating plant, to which it is indebted for many of its devices and constructional details. In a more precise determination it is a specialised combination for the specific purpose of fractional distillation designed on a balance of many practical and technical considerations. It necessarily varies with the character and quality of the oil to be distilled, the range of products obtainable or desired, local conditions, etc.; but apart from this, a wide review discloses considerable diversity in type and design as between different countries and refineries. It may be said, however, practically all descriptions of the general order, old and modern, large and small, elementary and complex, are based on simple principles of distillation, and the general trend of development here lies in the direction of the achievement of relatively small and more compact apparatus combined with a still greater regard to the fundamental and true principles of distillation.

It will be apposite to proceed from these generalisations to a few specific instances, illustrated by permission of Messrs. The Anglo-Persian Oil Co., Ltd.

The unit or "bench," as it is called by those engaged in the industry, shown in the photograph, Figure No. 9, is designed for the primary distillation or topping of crude from the now well-known Persian fields. The unit was not completed at the time the photograph was taken; it was, in fact, only placed in commission recently, but with the drawings reproduced in Figures 10 and 11 it may serve to give a clear idea of the general appearance and planning of a modern bench for the distilling of crude rich in low-boiling constituents.

There are eight boiler stills (unfortunately obscured in the photograph by the complementary plant behind them) fitted with internal flues and corresponding closely, except for a large vapour dome, with a Lancashire boiler, both in appearance and design. The photograph (Figure 12) shows two of a group of eight stills of this pattern recently shipped to Abadan. They are 37 ft. 6 ins. in length and 12 ft. in diameter. The stills are mounted in groups of four on substantial brick settings, which again follow conventional practice for the setting of Lancashire boilers. All benches of this kind operate continuously, and, taking them in the order in which oil flows from one to the other, each still is set at a lower level than the one preceding it. Any non-recoverable or incondensable gas given off during distillation and oil are burned under these stills. The upstanding vessels in the middle distance are dephlegmators and immediately below and in front of these is seen a battery of

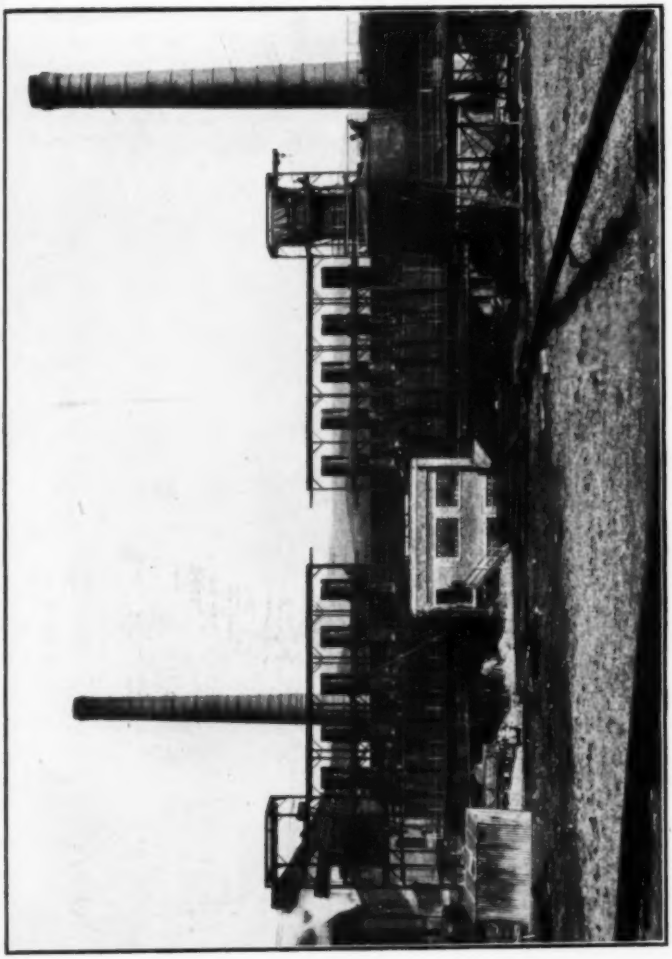


FIG. 9.

FIG. 12.

water-cooled condensers. Condensate from the latter gravitates through pipes which converge on to the upper chamber of the brick building in the foreground, where samples are periodically taken and gravities, temperatures and rates of flow systematically recorded. Here also, by means of a system of plugs giving on to a number of run-down lines, the condensate is diverted into a group of receiving tanks not shown in the photograph. Below the receiving or tail house is a pumphouse accommodating four electrically driven centrifugal pumps (Figure 13), two of which run continuously, discharging hot residual oil from the two lowermost of the groups of stills to two regenerators or pre-heaters mounted on steel framework, one at each end of the bench.

The line of approach to problems of large-scale distillation may be exemplified by consideration of the planning of these particular pre-heaters. A brief explanation and the drawing reproduced in Figure No. 14 will serve to make the manner in which they function apparent. An exchange of heat is effected as between the colder crude oil in its passage through the pre-heater to the first of one of the series of fired stills, and the warmer residual oil in process of discharge *via* one of the centrifugal pumps from the last of the series to storage or other point in the refinery area. Each heater is divided into five sections susceptible of being mounted or dismantled in order separately, and is fitted with what are in effect, though not literally, closely compacted coils of piping. Hot residual oil passes through the coils, the virgin crude circulates about them. Oncoming crude oil is delivered from charging tanks conveniently situated some little distance from the bench into the top compartment of the pre-heater, after traversing which it overflows to the succeeding compartment, where the direction of flow is reversed, and passing across the second compartment, it overflows again to the third. Flowing in this manner through the pre-heater in five stages it finally gravitates, now heated to the temperature approximately of boiling water, on to the first of the series of fired stills. Motion favourable to the release of gas and vapour into the space between the surface of the oil stream and the floor of an upper section, and exchange of heat between the two mediums, is imparted to the crude oil in its passage through each section by causing it to flow alternately under and over wiers extending across each compartment. A common vapour discharge pipe connects the vapour spaces with one to the battery of water-cooled condensers, where vapour generated in the pre-heater is condensed, gas passing forward through adsorption plant to a gas holder.

The hot residual constantly discharged from the last of the fired stills grouped with each pre-heater is pumped through the five sets of coils mounted in the heater in series. Regulation of the transfer of heat in each compartment is achieved by continuing the delivery

pipe from the pump vertically before the inlets to the several coils, and placing on this pipe at each inlet a simple device whereby the proportion of hot residual oil permitted to circulate may be controlled. Upon its emergence the latter mixes in the vertical main with the oil not so circulated before the inlet to a succeeding set of coils is reached, where a similar regulation may again be made.

Operating on Persian crude at an initial temperature of 60° F., and with residue run-off at 410° F., and in quantity about 60 per cent. by volume of the original crude, one pre-heater of this kind-measuring 10 ft. by 10 ft. by 20 ft. high, having a constant fluid content of 20 tons, will heat 750 tons of crude oil per day to a temperature of 200° F., free the crude of a large proportion of the incondensable gas given off in the distillation process, initiate active vapourisation and yields a flow of water-white distillate, effect an appreciable economy in fuel and obviate the necessity for water to cool the residue.

The heat recovered at the rate of throughput referred to is 40 per cent. of the total required for primary distillation, showing a thermal efficiency of 75 per cent.

It may be noted the arrangement of the heater provides a large heat exchange area with broad evaporative surfaces. The occasion for the former arises from the circumstance of oil being but a poor conductor of heat, and the provision of the latter is the outcome of attention to those fundamental principles to which reference has already been made and the general exigencies of the process of distillation. Touching on purely constructional features, there can be no occasion to enlarge here on the advantages of systematic planning and arrangement, uniformity and repetition in design, and the use of standardised and interchangeable constructional elements and devices. These pre-heaters as an instance are constructed of identical and interchangeable sections, the number of sections mounted together to form a complete unit varying with rating and thermal efficiency it is desired to obtain. Similarly in detail the nests of coils are built from constructional elements, of which a detail is given in Figure 15, and the same standardised element is employed in building condensers, coolers and heat exchange apparatus generally.

Figures Nos. 16 and 17 show another unit of plant recently erected at the National Oil Refineries, South Wales, for the re-distillation of once-run distillate. The full throughput capacity of this unit is 600,000 gallons per day. The stills, 40 ft. in length by 12 ft. in diameter, are steam heated and arranged in groups for either intermittent or continuous distillation. It will be observed the complementary plant here—analysers, dephlegmators, etc.—is more extensive and elaborate than in the case of units designed

for primary distillation. The bench, it may be remarked, was designed, fabricated and erected in ten months.

Washers.—The increase in the scale of operations leads, as in the case of distillation plant, in the direction of larger units, and although washers of 50,000 gallons capacity have been in use for some time in the U.S.A., it has not been the general practice here until recently to use larger units than 10,000 or 20,000 gallons.

The general arrangement of one of a battery of washers of 50,000 gallons capacity is shown isometrically in Figure 18. As will be seen, the shell is in effect a standard tank 25 ft. by 20 ft., with the addition of the conical bottom. The roof of the washer is, in this case, of ¼-in. plates, fitted with explosion doors and vacuum and pressure valves suitably placed. Arrangements are made on the explosion door frame for luting the joints with clay, which preserves gas tightness; at the same time the door can open freely in the event of an explosion. For the various fittings on the shell and top of washer cast-steel stools or mild steel pads are rivetted. A system of gauge glasses of ample bore is provided, and arranged with special fittings for rapidity in cleaning.

A suitable stair provides access to roof and upper fittings, and the interior of the washer is fitted with a system of spray pipes supported on steel gantries, these spray pipes insuring a thorough admixture of the oil and re-agents.

In order to guard against possibility of an explosive mixture forming inside the washer, steam is introduced by an automatic device.

The method of agitation is by means of a centrifugal pump drawing from the conical bottom and discharging through the spray pipe previously mentioned.

The capacity of the pump is 2000 gallons per minute, and efficient agitation is attained with much less energy consumption than with those arrangements where the bulk of the liquid is set in motion.

The washer is supported on a substantial concrete plinth comparatively close to the ground, so eliminating any structural supports which in the event of fire might collapse.

It is possible to arrange for the agitating pump to be used for charging and discharging the washer, but this involves complication of valves and pipe connections.

In conclusion, the author wishes to thank the A.P.O.C. for permission to reproduce drawings and photographs of items in their various installations.

Specification of Mild Steel Oil Storage Tanks 116 ft. diameter by 40 ft. deep, 2,600,000 gallons capacity.

Extent of Contract.—This contract under the terms of the general

specification attached includes the supply, delivery and erection of mild steel storage tanks 116 ft. diameter by 40 ft. deep, complete with all fittings as described in this specification and as detailed on drawings Nos. .

General.—The tanks are to be constructed of the best mild steel having an ultimate tensile strength of 28 to 32 tons per square inch with an elongation of not less than 20 per cent. in a test length of 8 ins.

The rivet steel is to have an ultimate tensile strength of 25–28 tons per square inch, with an elongation of not less than 25 per cent. in a test piece 8 diameters long between gauge points.

The manufactured rivets are to withstand a bend test as follows:—The shank to be bent cold and hammered through 180° till the two parts of the shank touch, without fracture on the outside of the bend.

Plating: Bottom.—Excepting the shaped plates at tank side the tank bottoms are to be made of rectangular plates $\frac{1}{4}$ in. thick. The thickness of all shaped bottom plates at tank side is to be $\frac{3}{8}$ in.

The five lowering holes in tank bottom, each 13½ ins. diameter, are to be fitted with a stiffening ring of 3 ins. by $\frac{5}{8}$ in. section rivetted to bottom plates, and a $\frac{3}{8}$-in. cover plate secured by sixteen $\frac{3}{4}$ in. diameter studs and welded round the outer edge; the studs are to be rivetted over on the underside. A detail of these lowering holes and covers is shown on drawing No. 839.

Body.—The body is to be built in eight strakes or rings, each approximately 5 ft. deep and consisting of fourteen plates round the circumference. The thickness of the body plates is to be in accordance with the following table:—

1st or bottom strake	$\frac{3}{4}$ in. plate.
2nd	$\frac{5}{8}$ in. „
3rd	$\frac{9}{16}$ in. „
4th	$\frac{1}{2}$ in. „
5th	$\frac{7}{16}$ in. „
6th	$\frac{3}{8}$ in. „
7th	$\frac{5}{16}$ in. „
8th or top strake	$\frac{1}{4}$ in. „

Crown.—The tank's crown is to be made of sheets $\frac{1}{4}$ in. thick rivetted together and to the top curb. When completed, the crown is to be perfectly gas-tight. Alternatively, the sheets to be arranged for electric welding. Tacking holes to be punched in all sheets for fixing during welding.

Curbs.—The curbs are to be of angle steel, the bottom curb 5 ins. by 5 ins. by $\frac{5}{8}$ in. and the top 3½ ins. by 3½ ins. by $\frac{3}{8}$ in. section. The curbs, each in fourteen lengths round the circumference, are to be set to the required radius and machined on the ends, the ends being joined by steel covers as detailed.

Riveting.—The details of rivetting for all joints are shown on drawing No. , and are to be in accordance with the particulars given in the following table:—

	Type of Joint.	Dia. of Rivets. in.	Pitch of Rivets. in.	No. of Rows.
1st strake vertical joint	butt	$\frac{7}{8}$	3	3
2nd	butt	$\frac{7}{8}$	3	3
3rd	butt	$\frac{7}{8}$	3	3
4th	lap	$\frac{7}{8}$	$3\frac{1}{2}$	3
5th	lap	$\frac{7}{8}$	3	2
6th	lap	$\frac{7}{8}$	$2\frac{3}{4}$	2
7th	lap	$\frac{7}{8}$	$2\frac{1}{2}$	2
8th	lap	$\frac{7}{8}$	$2\frac{1}{2}$	2
1st strake to 2nd circumferential joint	lap	$\frac{7}{8}$	3	1
2nd to 3rd ditto	lap	$\frac{7}{8}$	$2\frac{3}{4}$	1
3rd to 4th ditto	lap	$\frac{7}{8}$	$2\frac{3}{4}$	1
4th to 5th	lap	$\frac{7}{8}$	$2\frac{1}{2}$	1
5th to 6th ditto	lap	$\frac{7}{8}$	$2\frac{1}{2}$	1
6th to 7th ditto	lap	$\frac{7}{8}$	$1\frac{3}{4}$	1
7th to 8th ditto	lap	$\frac{7}{8}$	$1\frac{1}{2}$	1
All bottom plates together ..	lap	$\frac{7}{8}$	$1\frac{1}{2}$	1
Crown plates together ..	lap	$\frac{5}{8}$	$1\frac{1}{2}$	1
Bottom curb to side plates ..	lap	$\frac{7}{8}$	$3\frac{1}{2}$	2
Bottom curb to bottom plates	lap	$\frac{7}{8}$	$2\frac{1}{2}$	2
Top curb to side plates ..	lap	$\frac{7}{8}$	$2\frac{1}{2}$	1
Top curb to crown plates ..	lap	$\frac{7}{8}$	2	1

With the exception of the crown sheeting only, all rivet and bolt holes in plates and curbs are to be drilled to template; the rivet holes in the crown sheets may be punched. The rivet holes in bottom plates and in the horizontal flange of bottom curb are to be countersunk on the upper side, the rivets being hammered down on the countersunk or upper side and finished with button heads.

Excepting only the rivets in the bottom plates and horizontal flange of bottom curb, all rivets are to be hammered down outside.

The rivet holes in plates are to coincide accurately when the work is put together; no badly aligned work will be accepted by the purchasers, and no drifting will be allowed. The plates are to be properly drawn together before rivetting.

Caulking.—The edges of all plates of the bottom angle curb and bottom edge of top angle curb are to be planed for caulking metal to metal; no cloth or other jointing material whatever is to be used.

Plate Joints.—Where thinning of plates is necessary at joints, it is to be done by machine only. No heating or hammering is to be done.

Roof Framing.—The roof framing is shown on drawing No. , and comprises 14 main and 14 intermediate trussed radial rafters supporting rings of angle purlins of the sizes shown on the drawing. The main trusses are to be connected at the crown to a drum composed of a $\frac{3}{8}$-in. plate cylinder 3 ft. diameter by 1 ft. 3 ins. deep, and having top and bottom enclosing plates $\frac{3}{8}$ in. thick by 3 ft. and 3 ft. 4$\frac{1}{2}$ ins. diameter respectively, attached by angle rings, joints of which are to be welded solid. The vertical cylinder joint is to be covered by a 12 ins. by 8$\frac{3}{4}$ ins. by $\frac{3}{8}$ in. plate rivetted inside. The bottom ties of main roof trusses are to be bolted to a 3 ft. 6 ins. diameter by $\frac{3}{8}$ in. plate suspended from the crown drum by a 12-in. bore M.S. tube.

All intermediate rafters are supported at the inner end by a 6 ins. by 3 ins. by $\frac{3}{8}$ in. "L" bearers carried between main trusses.

All gusset plates in main and intermediate trusses are to be rivetted to rafters or bottom ties at contractor's works before delivery, and all connections made at site are to be bolted.

Purlin cleats are to be rivetted to rafters before delivery, except where the cleats occur at the rafter joint, when they are to be bolted.

One cleat at each end of the 6 ins. by 3 ins. by $\frac{3}{8}$ in "L" bearers is to be rivetted to main truss rafter and the other is to be bolted.

All purlins will be attached to cleats by means of $\frac{3}{4}$ in. diameter bolts.

Bolts generally are to be $\frac{3}{4}$ in. diameter.

The bottom ties of main trusses are to be braced together by one ring 2$\frac{1}{2}$ ins. by 2$\frac{1}{2}$ ins. by $\frac{1}{4}$ in. "L's" disposed beneath the longest vertical strut. Holes for bolts are to be drilled 1-16th in. diameter larger than the bolt, and when assembled all bolt and rivet holes are to be concentric. No drifting will be permitted.

Angle bracing, as detailed on drawing No. , is to be provided in one bay, *i.e.*, between two main trusses.

Fittings.—The fittings to be supplied and fitted are shown on drawing No. , and include the following:—One external stair in three flights from ground to tank top, as shown on drawing No. . A handrail of 1-in. galvanised tube is to be provided throughout the height and round all platforms.

Handrailing is to be fitted round the top circumference of the tank consisting of three 1-in. bore galvanised wrought iron gas tubes carried by W.I. standards bolted to the top angle curb at 6 ft. centres.

Twelve of the standards are to be extended by 1-in. galvanised W.I. gas tube to 9 ft. high from base and fitted with sharp points for lightning conductors.

Four top manholes are to be supplied and fitted with a clear opening of 18 ins. by 15 ins. with cast iron frame and bolted on

cover. The frame joint to the tank top and cover joint to frame are to be made with $\frac{1}{4}$ in. thick asbestos millboard. The manholes are to be supported from the purlins as shown on drawing No.

Two side manholes with a clear opening of 24 ins. by 18 ins. are to be supplied and fitted in the bottom plating ring. The frame is to be of cast steel rivetted to the tank plate and welded round the outer edge. The cover is to be of $\frac{7}{8}$ in. mild steel plate machined for joint and jointed with asbestos millboard $\frac{1}{4}$ in. thick.

One 12-in. cast steel stool for inlet connection to tank, to be rivetted to tank side. Flanged to B.S.T. No. 2.

One 12-in. cast steel stool for outlet to be rivetted to tank side. Flanged to B.S.T. No. 2.

Three 4-in. dipping door fittings with the necessary bolts, nuts and joints.

Three cleaning doors, 16 ins. diameter cast steel body and M.S. plate cover.

Three 3-in. sludge connections are to be rivetted to the tank bottom and fitted with a 3-in. sludge pipe and 3-in. flanged cast iron, roundway, gland pattern, sludge cock.

Partial Erection and Marking.—One tank bottom with bottom angle curb and first plating ring as also one complete tank roof with top plating ring are to be erected complete before despatch. The remainder of the plates are to be laid out and the whole carefully marked for re-erection.

Painting.—Before despatch from contractor's works, all parts of the roof framework are to be separately painted with one coat of "Duroprene" varnish, as also the inside surface of all roof sheets.

Erection and Testing.—The bottom of the tanks to be rivetted up about 3 ft. from the ground together with the bottom angle curbs and the first tier of side plates, the landings having first been properly cleaned of dirt and rust. The contractors to provide all necessary wooden blocks for holding up the tank bottoms, making due allowance for the additional weight of water when tests are being made. After all joints between the plates themselves and between the plates and bottom angle curbs have been thoroughly caulked inside and outside, the bottoms to be tested with 1 ft. of water. Leaky joints to be re-caulked and leaky rivets to be cut out and renewed, as directed by the purchasers' engineer. After the bottoms have been passed as tight by the purchasers' engineer, each is to receive two coats of either "Bitumastic" solution or hot tar, to be supplied by the contractor. In order to neutralise any acid which may be present in the tar a suitable proportion of lime is to be added before applying to tank bottoms. Each coat to be thoroughly dry before the next is applied. Before applying the "Bitumastic" solution or tar all scale and rust must be removed

from the tank bottom. After coating, the bottoms are to be lowered on to the foundations. The erection of the side plates and roof may then be proceeded with, but all side plates and roof frames must have been bolted into position before rivetting is commenced. After rivetting, all joints inside and outside must be thoroughly caulked and the tanks are then to be tested with water to their full height. All leaky seams and rivets are to be marked, and after the water has been drained off, the seams must be re-caulked and the leaky rivets cut out and renewed to the satisfaction of the purchasers' engineer. If necessary, the tanks must again be filled with water, and this must be repeated if required until the purchasers' engineer is satisfied that each tank is satisfactory. The water must remain in the tanks for at least six days, when the tank is to be drained and the whole interior thoroughly cleaned out. While the water is in the tank the roof must be tested for gas-tightness by compressed air, and must remain tight at a pressure equal to 2 ins. of water. All seams of roof sheets are to be tested for air leaks with a solution of soap and water. The contractor must provide means for supplying the compressed air. The erection of the tanks will not be considered as completed until all the fittings specified are erected in position.

DISCUSSION.

The Chairman said the paper was a most valuable contribution to the proceedings of the Congress.

Mr. H. Barringer said he had listened with great interest to the paper, and there were one or two features in it upon which he should like to make a few remarks. He agreed with the author in one case with regard to the application of the centrifugal pump for pipe-line work, which he thought was unique. He had known that the author had been for many years a great advocate of the centrifugal pump and had once tried to convert him to the view that it was the right thing to fit in a tanker, but he had always asked him how he was going to drain out, because that was a difficult matter in connection with the centrifugal pump, and it might be necessary to fit another pump for the draining work. He concluded that the installation was running satisfactorily and should like to ask the author whether he used a bronze impeller or a steel one, or whether there was any question of the action of the oil on the impeller running at that high speed. With reference to the vacuum and compression relief valves, he had used the spring loaded valve on board ship for some time and had had no particular difficulty, although he believed a dead weight loaded valve on something of the same lines was safer, and possibly for storage

tanks was better than trusting to a spring. The arrangement of swing pipes he also thought was good; it did away with the necessity of obtaining a gas-tight joint with a lifting cord or chain, but apparently from the drawing it was quite a short pipe and the usual practice was to fit a pipe which would reach the centre of the tank. No doubt that could be provided for if found necessary. With reference to the utilisation of steam from the high-pressure exhaust of the turbine, that was not altogether novel, but he thought in its application to petroleum installations it was quite new. He had never seen it used before in this connection, although it was used in some factories. There was no doubt a great saving by utilising some of that steam when the electric power was varying. With regard to fire, he should like to ask the author if he had any experience with Foamite, and whether it was fitted to any of the installations. He had been rather taken with the flat roof. He had never heard the argument put forward by the author before, but he thought it was very sound and might apply to any roof. The Americans liked to have the flat roof with water on the top for their tanks; it was an easier roof to construct and there was no difficulty in making the flat roof and most likely it would be desirable in some cases. He wished to bear testimony to the Chairman's remark that the paper was a very valuable one and would be more valuable when one had time to digest it. The Section was greatly indebted to the author for having given such a very interesting paper.

Mr. G. W. E. Gibson also agreed that the thanks of the Section were due to the author for his original and valuable paper. Like all pioneers, Mr. Dalley was enthusiastic and there was perhaps one point that he had overlooked, namely, that he had not given sufficient warning against using centrifugal pumps for oils that were not as perfect as the oils dealt with regularly by him, which might be called perfect oils from the pumping point of view. He did not think the author would care to use a centrifugal pump for Panuco crude. With regard to the pipe-line pump he should like to ask how the sand in the crude oil was dealt with, because he felt almost certain that it was not got rid of, and that with the pipe-line pump running from 1600 to 2100 revolutions per minute there was a fairly high percentage of sand in the oil. No doubt some means were used to filter the oil, but he did not think the sand was all taken out. Probably the author had adopted the steam turbine drive because an electric drive in this case was impossible, or, rather, was not sufficiently economical. It must have been a very great problem to provide an efficient condenser in that particular locality. The cooling pond and condensing plant must have cost quite a large sum of money; probably the

steam plant was lower in price than an electric power station in that particular case.

Mr. A. Beeby Thompson said the author in his paper had referred to many important matters, including the utilisation of centrifugal pumps for pipe-lines. For many years that particular type had been sought for pipe-line purposes, as theoretically it presented a combination of almost ideals. It was of light weight, comparatively cheap in cost, occupied little space, and gave constantly sustained delivery. Engineers had long sought a turbine type of pump which would deal with small quantities at high pressure, but apparently it was almost impossible to obtain this combination which characterised most pipe-line duties. When it was necessary to provide for wide differences in viscosity due to changes of temperature, it was found that the turbine pump presented difficulties, especially where prime movers with only restricted variations of speed were used. On one or two occasions he had been nearly induced by manufacturers to place an order for rather important installations, but on seeking the advice of those with experience he was led to fall back upon the old plunger types owing to the limited latitude of the turbine. It seemed to him that a turbine pump capable of working under wide variables was extremely difficult to design, and in the case of viscous oils, where there was a difference of temperature between 60° and 120° F. there were enormous differences in viscosity. Some of the oils which had to be dealt with were practically solid during the night, and unless elaborate arrangements were made for heating that oil up he was afraid the pump would work exceedingly erratically if it worked at all. Any information on this subject would be welcomed, as we all wished to introduce the rotary type of pump, which works so well under constant conditions. One other matter raised in the paper was of importance, namely, the prevention or preservation of benzine and light spirits from oil in tanks. In America arrangements were introduced for the breathing of the tanks through some absorbing apparatus which collected light spirits. Whether those would come into practice or not he did not know. There were no insuperable difficulties as in introducing such appliances, but the experiments made had, he believed, not been altogether satisfactory. An apparatus into which the gases could breathe was a little complicated, and there was the question also of the recovery of the products. One point upon which he would like the author's views was the use in tanks of a floating roof to prevent evaporation. It seemed to him that this was a very feasible and sensible idea entailing very few of the troubles and risks some of the other schemes involved.

Mr. H. Barringer said he had once fitted a gasometer to take

off the gases so that during the night they would condense, but in this country it was useless. In a tropical country it might be of value.

Mr. E. Lawson Lomax said he wished to support the author in many of his remarks. He had had a considerable amount of experience in the utilisation of some of the improvements in refinery work that had been developed by the author. He was not altogether in agreement with him in many things. First of all with regard to the vacuum and pressure valves for the tank that had been described, they suffered from the same defects that many other accessories did—namely, that they required looking after, and in many cases they were forgotten and then they were no better than a plain roof on the tank. With regard to the lagging of steam lines for heat conservation, a photograph had been shown on the screen of an installation for steam distribution. About three years ago there was a very heavy snow-storm, followed by a very heavy frost, where this particular line was installed, and he had seen icicles on the main steam line hanging for two days, which seemed to show the efficiency of the lagging of that steam line. Another point he should like to mention was the question of the agitation in the washers by pumps. The author claimed that less power was required for agitation by means of pumps than by mechanical means such as paddles. Possibly less power per unit of time was required, but he believed that in most cases it would be found that more time was required for the same treatment with pump agitation than was required with paddle agitation. He did not think the treatment was so efficient with pump agitation as with paddle agitation. Apart from those few points he was quite in agreement with all that that had been said in the paper, and he thought it was a very valuable contribution to the literature of the subject.

Mr. Alfred W. Nash wished to add his small tribute of praise to the author and at the same time ask for some further information. It was thirteen years ago since he was on the Persian fields and refinery, and he had been very much amazed at the improvements which had been brought about since he was there. Praise was not only due to the author, but to the Anglo-Persian Oil Company for allowing details to be published, because this information was usually treated as being of a confidential character by oil companies. With regard to the floating tank roof referred to by Mr. Beeby Thompson, he should like to hear what the author had to say further on the subject. Many glowing reports had reached him from America as to the efficiency of such tanks. One company had sent him a copy of a certificate from an insurance company to the effect that one of those tanks with a floating roof

containing crude oil with a top dressing of gasoline had had fire lighted on the outside and eggs boiled at the top and yet no fir had occurred. It would certainly appear, at first sight, as thoug the vapour pressure must of necessity be decreased and the ris of loss by evaporation consequently decreased. He should als like to ask the author if he had considered the use of spherica tanks for holding products such as gasoline. He believed the were being used in America, and naturally they could stand ver much higher pressure than the ordinary tank. With regard t caulking the roof, which was necessary owing to the "breathing of the roof, he should be glad to know whether the author fel welding was preferable to caulking in the side strakes of the tank bearing in mind the difficulty of caulking tanks and keeping ther tight in connection with kerosene and gasoline. The draw-o swivel pipe and tank bottom seating was certainly very ingenious but he noticed that the bottom edge of the suction hole was onl about 4 ft. from the bottom, and he was wondering whether ther was a possibility of drawing in sludge, bearing in mind that ther was bound to be a certain amount of eddying around the suctio There was one interesting point he should like to hear about i connection with the pumping stations. He took it from the de scription that the delivery of No. 1 station was the suction of No. 2 If such were the case, if the steam for the turbine were closed o to work the sprinklers, he should like to know what happened a the previous station to the one which had caught fire.

The author was to be congratulated on having attained such high efficiency on his turbine plant when the ideal efficiency o such a plant would be, he supposed, somewhere of the order o 75 per cent.

He should like it confirmed that this figure of 50 per cent. wa worked out on the assumption that the prime mover was a back pressure turbine as distinct from a condensing unit. With regard to the non-recovery gases being burned, it would be interestin to know whether the gases were stripped previous to burning, and if not, whether the author considered that such an experiment would pay or not. The question of the efficiency of the residuum pre-heater was one that had interested him considerably becaus last year he toured several countries and saw many refineries amongst which were probably four of the biggest and most moder in the world, and bearing in mind that residuum pre-heaters onl were used by the author, the thermal efficiency of 75 per cen was a very splendid result.

The best results he had obtained from any one bench when in specting those refineries mentioned was 42 per cent., and in tha case the temperature of the residuum leaving the pre-heater wa 100° F., which he calculated was about the temperature it le

he author's plant. He should like to know the percentage of light istillates obtained from the residual pre-heater.

The system of agitation in the washers described by the author as a great improvement over the old method of mechanical or ir agitation, and he thought some information as to the refining gent used would be of interest to members, as he presumed sulhuric acid was not used as there appeared to be no arrangement r drawing off the tar.

Mr. C. Dalley, in reply, said that Mr. Barringer had reverted an old topic of discussion between them—viz., the drainage of nkers. When the electrically driven pumps were installed on he tankers, he had another conservative friend, also interested in nker work, who made it a condition that if centrifugal pumps ere installed on board the tankers, a small reciprocating pump ould be included so that the ship could be quickly drained. Whether this draining device was found to be absolutely necessary e was unable to say.

With regard to the remarks about the vacuum and pressure alves and the ordinary valve fitted for ventilation of ships' tanks, he conditions were not quite comparable. There were 10,000 or 2,000 sq. feet of thin roofing on a big storage tank and this roof as rendered gas-tight by welding or more common methods, nd if there was a vacuum in the tank, so small that it would not e possible to adjust it with spring control, the roof would be in nger of collapse. During the construction of the works at Llanarcy the testing of a small tank was being carried out in the usual ay. The ventilators and other outlets were blanked off, and during he water test compressed air was blown in and soapy water brushed ver the roof seams to test the roof for gas tightness. Having atisfactorily passed the test, the contractor was instructed to empty he tank and replace the fittings. Opening a 6-inch valve to run f the water with the ventilators still blanked off, the roof immeiately collapsed. If there was to be real gas tightness in the roof here must be some definite method of protecting the roof against ny excessive extra pressure. With regard to the swivel pipe, t was true it was comparatively short. In the majority of cases, ven with very dirty crude oil, sludge should not be allowed to ccumulate more than one or two feet up in the tank, and it was hen time to clean the tank out. A number of tanks half full of ludge reduced the storage capacity proportionately. Mr. Baringer had mentioned Foamite; he had studied quite a number f those devices. One of the greatest weaknesses, which he thought as admitted by the people who made the material, was its instaility, particularly in tropical climates. Some experiments had een made recently in service tests, and one of the various forms

of Foamite, when an emergency arose, was not in the form in which it would function. Foamites, even in a temperate climate, required considerable and continuous maintenance before they could be considered properly reliable. Mr. Gibson suggested he should try a centrifugal pump with "Panuco" crude. He knew what Panuco crude oil was, and suggested that in such a case it was not a pump that was necessary, but a steam "navvy." He thought experience went so far as to show that if it was necessary to heat up any of the heavy oils to pump them with an ordinary reciprocating pump he could guarantee, except in exceptional cases, to provide a centrifugal pump that would pump the oil.

With regard to sand and other foreign material, an ordinary strainer was provided on the suction side of each pump. In this particular instance they were not troubled with any great percentage of sand or foreign material which would have a wearing effect. So far as the wear and tear on the impellers were concerned there had not been any difficulty in this connection, and they had been in use now for three years. He had seen a biscuit-tin full of pieces of rock as large as walnuts which had been through one of these pumps and the pump was still running, which indicated that this type of pump was more robust than generally imagined.

With regard to Mr. Gibson's query regarding the decision to instal the steam turbine drive, the question of electrical operation was very fully investigated, but on many grounds this could not be justified under the conditions then existing, and it would be difficult to make out a case even to-day. The question of the prime mover was one of absolute reliability. He had considered with his colleagues various drives, including oil-engines, as prime movers, but experience showed that for reliability and continuous operation oil-engines did not favourably compare with steam turbines. The saving in fuel with an oil-engine compared with the steam turbine outfit was negligible against the losses due to possible interruption in pumping. When one remembered that a pipe-line functioned continuously, operating 168 hours a week and for 52 weeks in the year, it would be appreciated that reliability was the prime consideration.

With regard to the limitations of centrifugal pumps, a point raised by Mr. Beeby Thompson, the safest thing to do in all pumping propositions was to consider them individually. There were cases where he would not hesitate to instal centrifugal pumps, and there were also cases where he would not consider them. It was true they had certain limitations, particularly with regard to small quantities as against big heads, but within certain limits they had a flexibility which an ordinary reciprocating pump had not.

With regard to the question of loss by evaporation, if there was an oil stored in a gas-tight tank for a considerable period of time

and a steady pressure was maintained on it such as he suggested, the loss by evaporation was undoubtedly considerably reduced, but where there was a tank continually being emptied and filled it became quite a different problem. A case might be taken of, say, fifty tanks with a gas-holder and a common atmosphere which was used for all the tanks when the tanks were emptied or filled. Considerable saving might be effected, but it became a purely economical calculation as to whether the saving effected would give a return on the outlay. There, again, it was a question for individual investigation. With regard to the floating roof, he developed a floating roof in 1915. It was necessary to have some sort of joint between the walls of the tank, and whatever the arrangement might be there was bound to be a little leakage past the joint. Very few, if any, of the so-called cylindrical tanks were really cylindrical, except perhaps when full, and apart from the variation in side strakes of the tank, the bottom was perhaps circular and the top oval, and there had to be a fair margin for the joint. Should gas escape through the joint when a tank was nearly empty of liquid, the whole of the tank contents on the top of the roof became an explosive mixture, and he was not sure that was not more dangerous than if the vapours were contained in an ordinary roof. He believed the chief difficulty with a floating roof was making a suitable joint between the floating roof and the wall of the tank. In America where they stored oil for considerable periods they had used a patent heavy liquid which was supposed to seal the oil in the tank and so prevent evaporation, but he believed that was only useful within limits—that the oil began to gasify and bubbles of gas made holes in the blanket lining from whence gas leaked almost as badly as if no protection was provided; further, water dropping through a leaky roof punctured the lining, producing the same effect. He had had no experience of spherical tanks and had not considered such tanks for gasoline storage. Spherical tanks would be expensive to make of any size.

With regard to electric welding, four or five years ago he thought that by to-day large storage tanks would exist with no rivets in them at all, but "all electrically" welded. In electric welding, however, great dependence had to be placed upon the welding operative. The welding might look all right, but it might be a most imperfect weld. He thought the development would be gradual first, that the roofs would be welded, and then probably the two top side strakes, having rivets at about six inches pitch for safety until a little more was known on the subject. In his opinion it would be a long time before the large oil storage tanks could be wholly welded.

With regard to the operating of pumps in series, it should be remembered that there were forty miles between each of the stations,

and that in the case of shutting down, starting up and any other adjustment which might be made, a certain time would be available for action in the case of emergency. Shut-downs had occurred due to the overspeed device on the turbine tripping. It was possible to shut down an intermediate station and pump right past it at a lower rate. There was no difficulty and all the adjustment was done by the speed variation on the turbine governor. Mr. Lomax had spoken of the pressure and vacuum valves not being satisfactory because of the attention they required. He did not think anything had been designed yet in such items as tank fittings, etc., that did not need a little attention. He knew that if the valves had a minimum of attention they would function all right. The point he wished to emphasize was that it was dangerous to have a gas-tight roof without some very positive protection for it. Another example had come under his notice where damage occurred due to pumping oil into a tank when the outlet for air was closed. The roof rose under the pressure and pushed out the sides of the tank. There was not much damage done, but it served as an object lesson as to the danger unless the tanks were properly protected.

With regard to the question of agitation, it was admitted that this operation was prolonged with a centrifugal pump, but it was

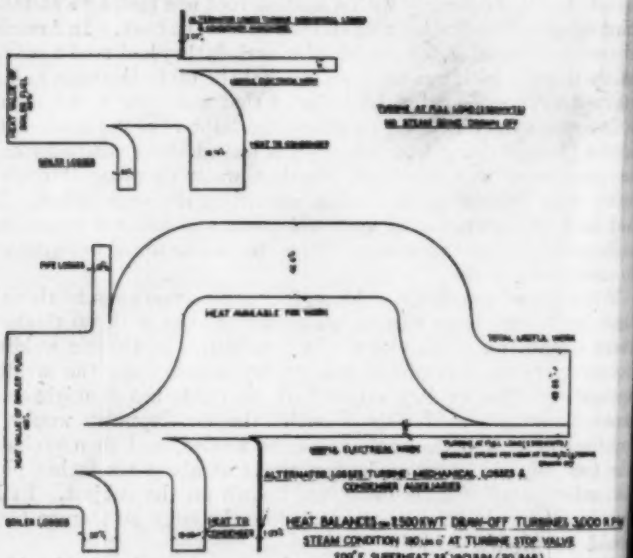
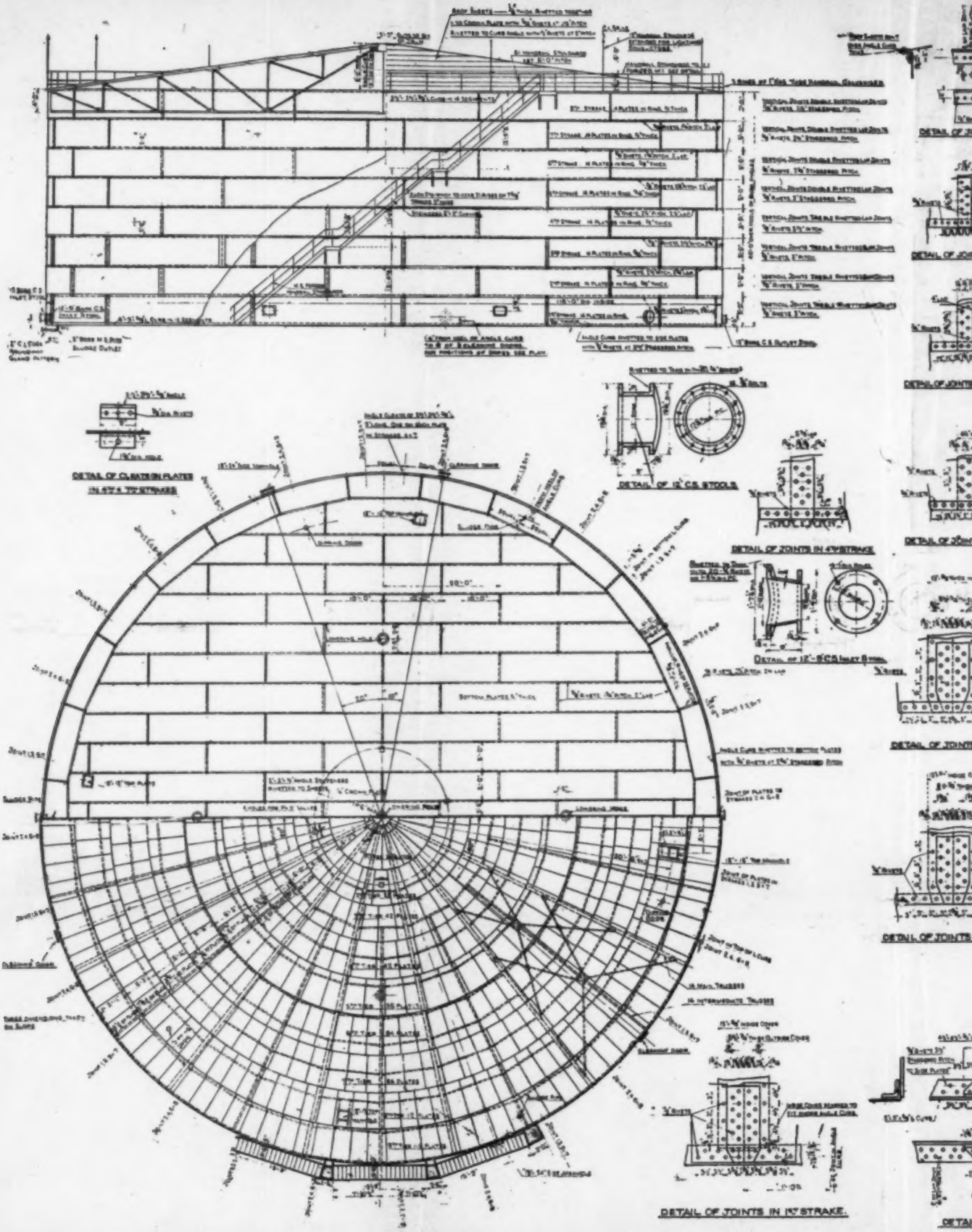


FIG. 19.


DETAIL OF CLEATING PLATES IN 4TH STRAKE
DETAIL OF 12"-0" C.S. STOOLS
DETAIL OF JOINTS IN 4TH STRAKE
DETAIL OF JOINTS IN 10TH STRAKE.

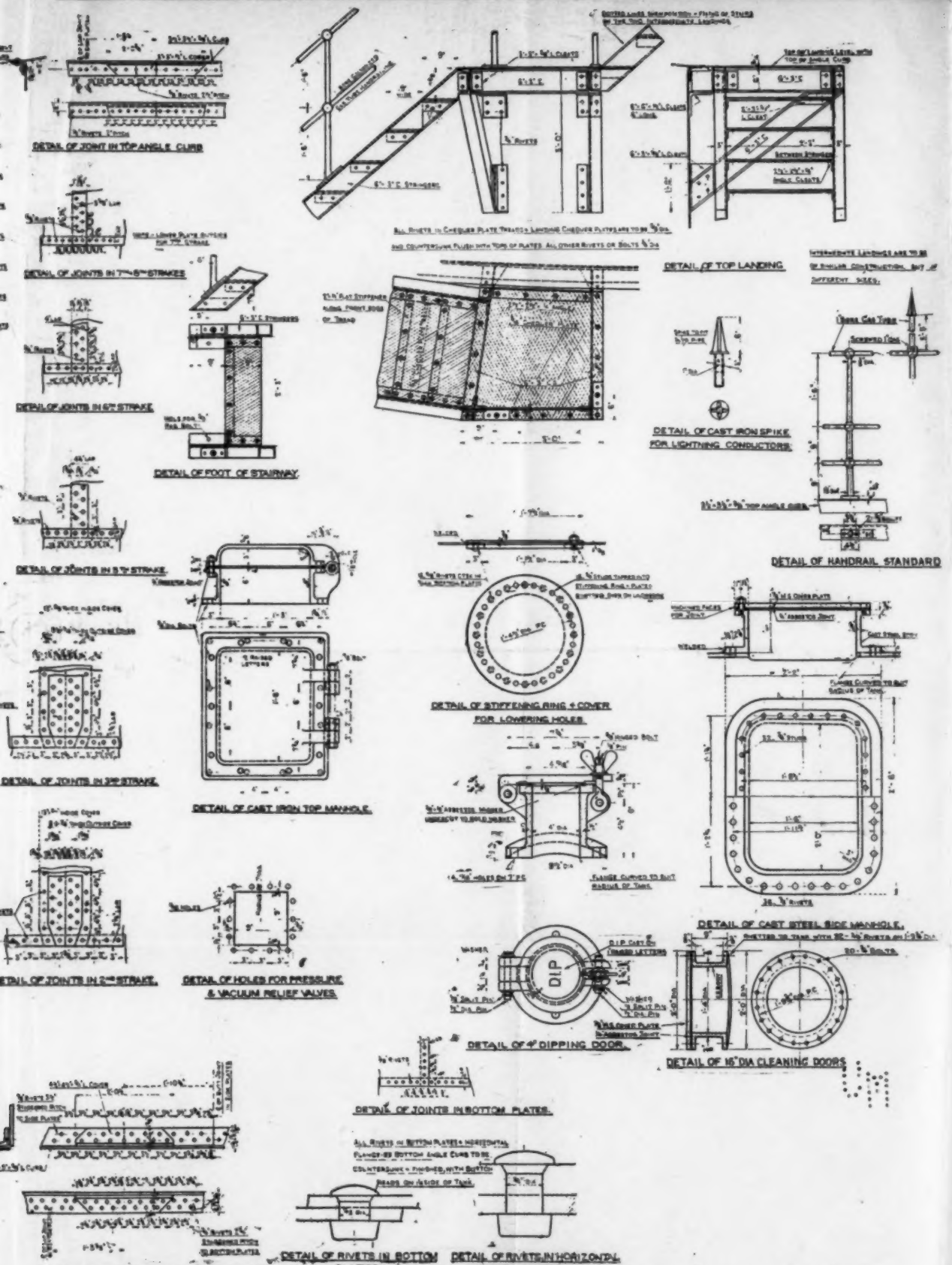
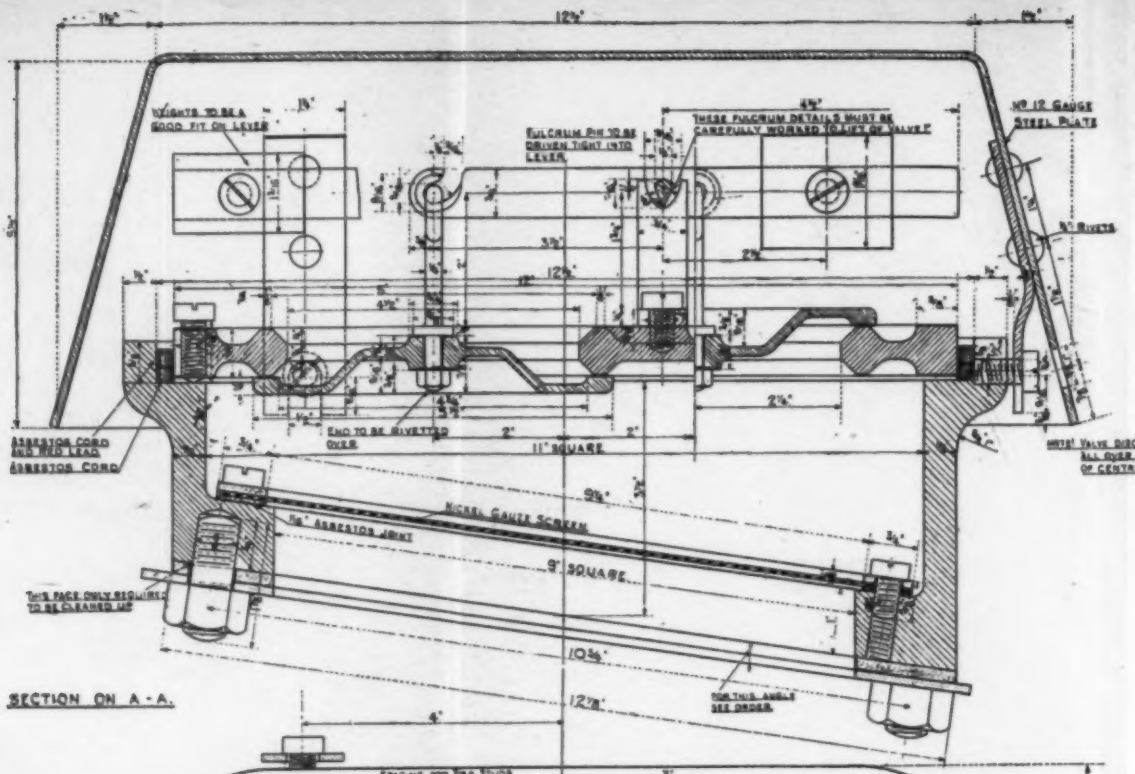
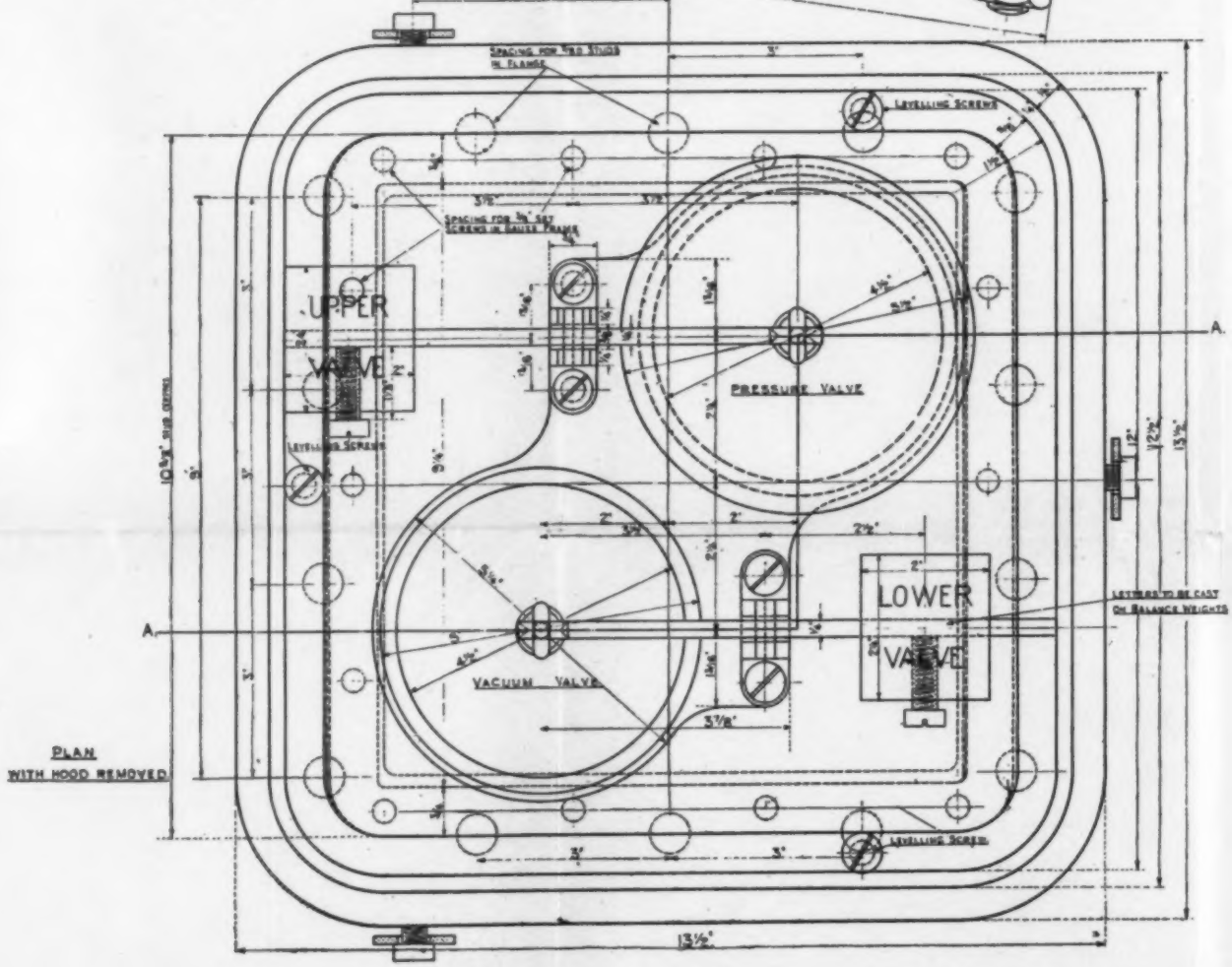
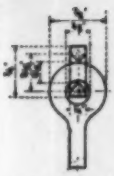

DETAIL OF JOINT IN TOP ANGLE CURB
DETAIL OF JOINTS IN 7TH & 8TH STRAKES
DETAIL OF JOINTS IN 6TH STRAKE
DETAIL OF FOOT OF STAIRWAY
DETAIL OF JOINTS IN 5TH STRAKE
DETAIL OF JOINTS IN 3RD STRAKE
DETAIL OF CAST IRON TOP MANHOLE
DETAIL OF JOINTS IN 2ND STRAKE
DETAIL OF HOLES FOR PRESSURE & VACUUM RELIEF VALVES
DETAIL OF TOP LANDING
DETAIL OF CAST IRON SPIKE FOR LIGHTNING CONDUCTORS
DETAIL OF HANDRAIL STANDARD
DETAIL OF STIFFENING RING & COVER FOR LOWERING HOLES
DETAIL OF CAST STEEL SIDE MANHOLE
DIP
DETAIL OF 4" DIPPING DOOR
DETAIL OF 16" DIA CLEANING DOORS
DETAIL OF JOINTS IN BOTTOM PLATES
DETAIL OF JOINTS IN BOTTOM ANGLE CURB
DETAIL OF RIVETS IN BOTTOM PLATES
DETAIL OF RIVETS IN HORIZONTAL FLANGE OF BOTTOM CURB

Fig. 2.


WEIGHTS TO BE A GOOD FIT ON LEVER
FULCRUM PIN TO BE DRIVEN TIGHT INTO LEVER
THESE FULCRUM DETAILS MUST BE CAREFULLY WORKED TO SIZES OF VALVE
No 12 GAUGE STEEL PLATE
ASBESTOS CORD
ASBESTOS CORD
END TO BE RIVETTED OVER
11" SQUARE
NICKEL GAUZE SCREEN
9" SQUARE
10¾"
12⅞"
SECTION ON A-A.


SPACING FOR ⅜ STUDS IN FLANGE
LEVELLING SCREWS
SPACING FOR ⅜ SQ SCREWS IN GAUZE FRAME
UPPER VALVE
PRESSURE VALVE
LOWER VALVE
VACUUM VALVE
LETTERS TO BE CAST ON BALANCE WEIGHTS
13½"
PLAN
WITH HOOD REMOVED

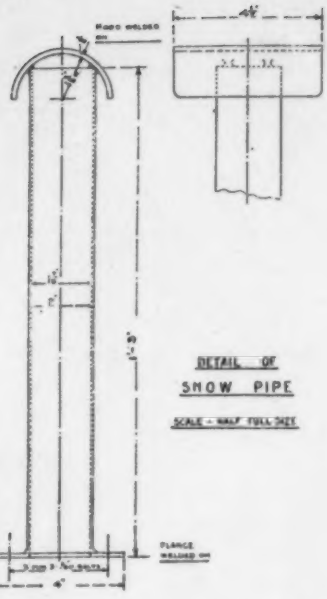


DETAIL OF LEVER AND VALVE CONNECTION.

ASSEMBLY.

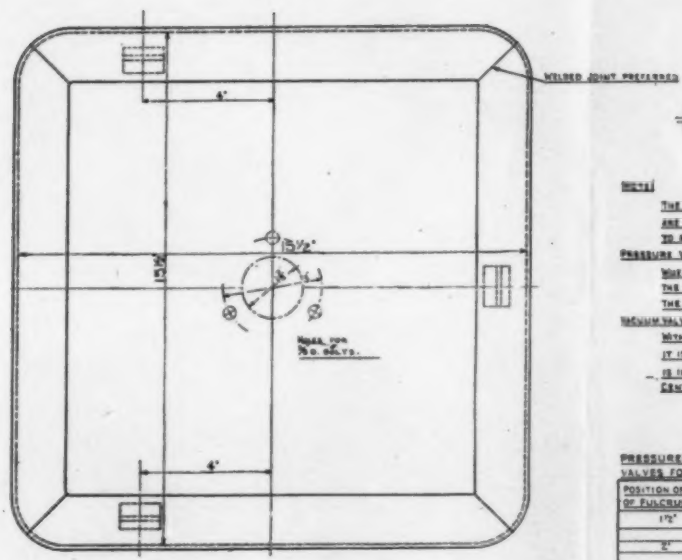
DESCRIPTION	METAL	No OFF	DIMENSIONS
BODY	CAST IRON	1	
VALVE PLATE	CAST IRON	1	
VALVE DISCS	GUN METAL	2	
BALANCE WEIGHT	CAST IRON	1	
" "	CAST IRON	1	
WEIGHT LEVERS	MILD STEEL BAR	2	⅜" × 1¼" × 8¼"
FULCRUM PINS	MILD STEEL	2	
FULCRUM BRACKETS	CAST IRON	2	
VALVE SPINDLES	MILD STEEL	2	
GAUZE FRAME	MILD STEEL BAR	1	
GAUZE SCREEN	MONEL	1	10" SQUARE
ADJUSTING SCREWS	BRASS	3	⅜" × 1" LONG
SET SCREWS	BRASS	21	⅜" × ⅜"
STUDS & NUTS	STEEL	14	⅜" × 1¾"
NUTS	STEEL	2	⅜"
SET SCREWS	BRASS	2	⅜ × 1¾"
JOINTING SQUARE	ASBESTOS	1	⅛" THICK
PACKING	ASBESTOS CD		8 FEET
HOOD (COMPLETE)	MILD STEEL PLATE	1	1/8 12 GAUGE
TANK JOINTING	ASBESTOS	1	⅛" THICK

NOTE! VALVE DISCS TO BE ROUGH TURNED ALL OVER. VALVE FACE AND BACKS OF CENTRE BOSS TO BE THEN SMOOTHED.



DETAIL OF SNOW PIPE

SCALE - HALF FULL SIZE



PLAN OF STEEL HOOD.

SCALE. HALF FULL SIZE.

PERFORATIONS FOR SNOW PIPE ATTACHMENT INDICATED BY DOTTED LINES.

NOTE!

THE DIMENSIONS GIVEN FOR THE BALANCE WEIGHTS ARE APPROXIMATE AND THE WEIGHTS ARE TO BE PROPORTIONED TO ACHIEVE THE FOLLOWING CONDITIONS.

PRESSURE VALVE.

WHEN THE BALANCE WEIGHT IS IN THE POSITION SHEWN ON THE DRAWING (i.e 3½" FROM FULCRUM TO CENTRE OF WEIGHT) THE VALVE AND WEIGHT ARE TO BE IN BALANCE.

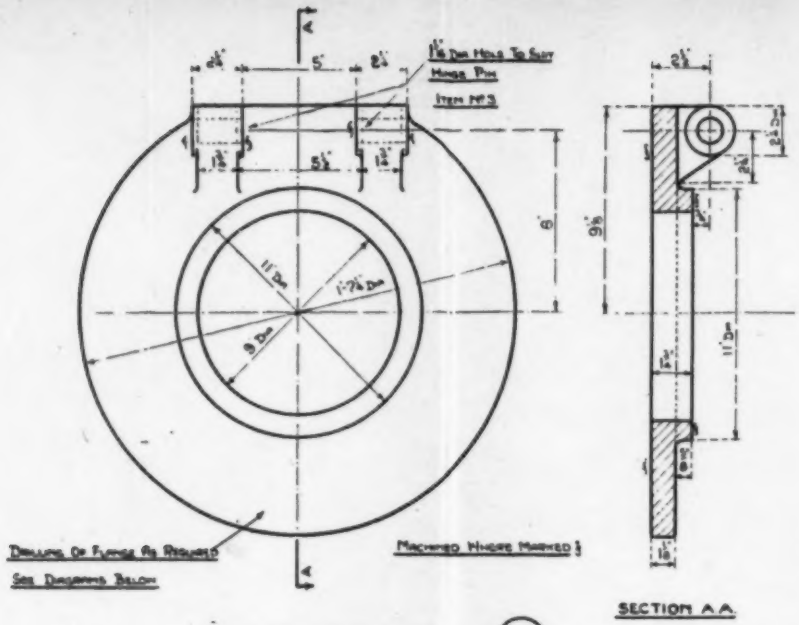
VACUUM VALVE

WITH A "7 OZ WEIGHT" PLACED ON THE VALVE DISC IT IS TO BE IN BALANCE WHEN THE BALANCE WEIGHT IS IN THE POSITION SHEWN i.e 2½" FROM FULCRUM TO CENTRE OF WEIGHT.

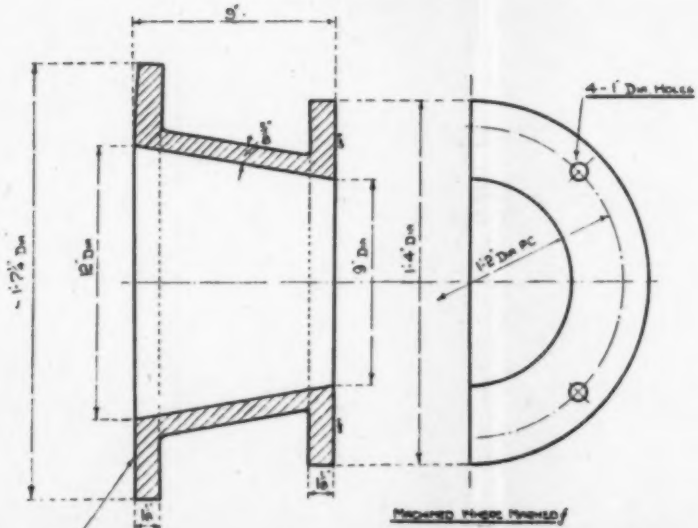
PRESSURES IN LBS PER SQUARE FOOT REQUIRED TO OPEN VALVES FOR VARYING POSITIONS OF BALANCE WEIGHTS.

POSITION OF BALANCE WT/CENTRE OF FULCRUM TO CENTRE OF WEIGHT	PRESSURE VALVE LBS PER SQ. FT.	VACUUM VALVE LBS PER SQ. FT.
1½"	5·93	
1¾"	4·84	
2"	4·14	
2¼"	3·45	
2½"	2·75	·25
2¾"	2·07	1·18
3"	1·38	2·12
3¼"	·7	3·13
3½"	IN BALANCE	4·14

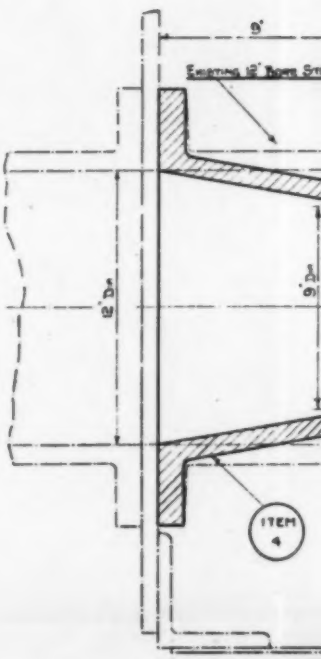
Fig. 3.


1½ Dia Holes To Suit Hinge Pin Item No 3
Drilling Of Flange As Required See Drawing Below
Machined Hinges Marked J
SECTION A.A.

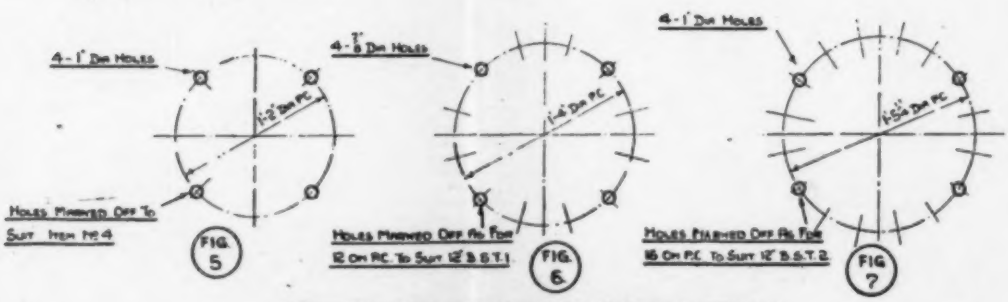
CAST IRON BACK PLATE (ITEM 1)


4 - 1" Dia Holes
Machined Hinges Marked J
This Flange Drilled On Site
Flange Curved To Inside Radius Of Tank (56'-0") Clamped Up But Not Machined To Be Riveted To Tank But Not Caulked

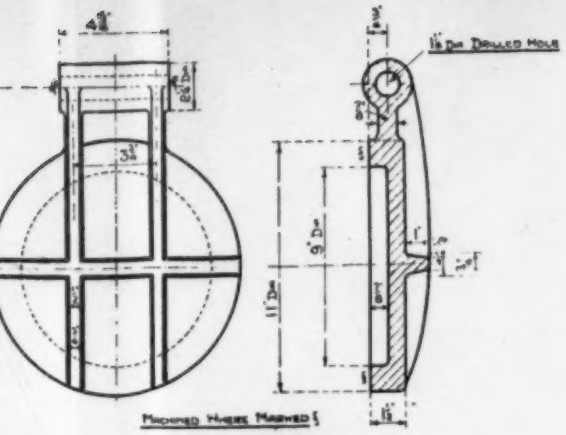
CAST STEEL STOOL (ITEM 4)



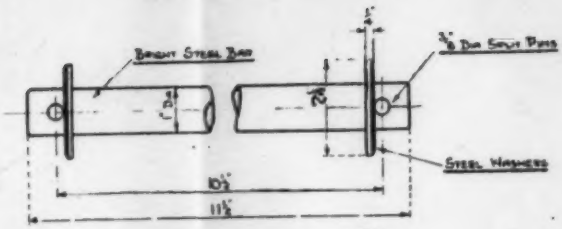
SECTION


4 - 1" Dia Holes
Holes Marked Off To Suit Item No 4
FIG 5
4 - 1" Dia Holes
Holes Marked Off As For 12 On P.C. To Suit 12" B.S.T.1
FIG 6
4 - 1" Dia Holes
Holes Marked Off As For 16 On P.C. To Suit 12" B.S.T.2
FIG 7

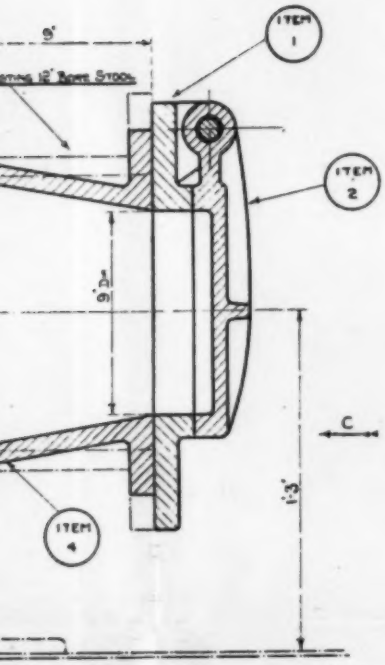
DIAGRAMS OF DRILLING FOR FLANGE ITEM No 1



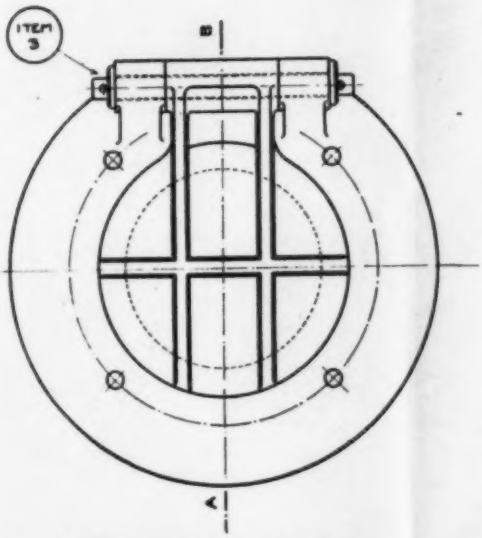
CAST STEEL FLAP (ITEM 2)



STEEL HINGE PIN (ITEM 3)

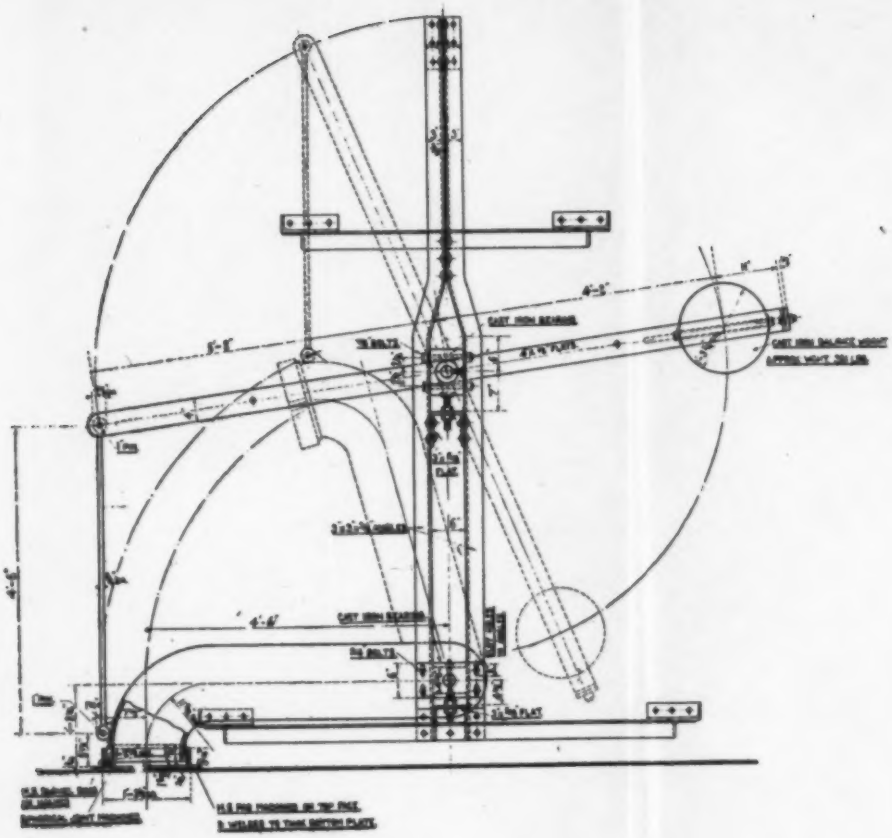


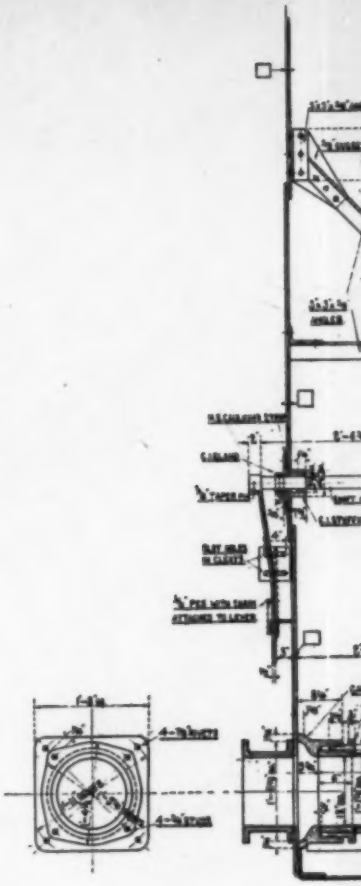
SECTION THRO A.B

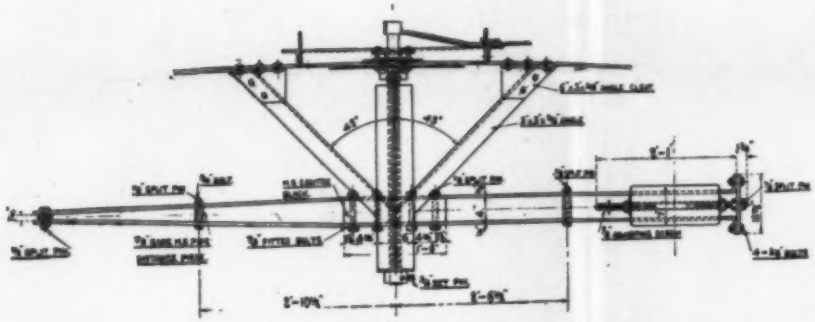


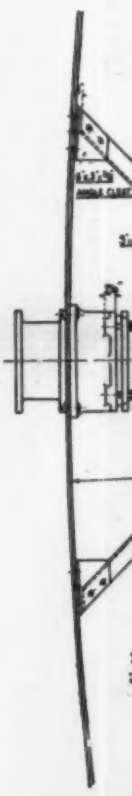
VIEW IN DIRECTION ARROW 'C'

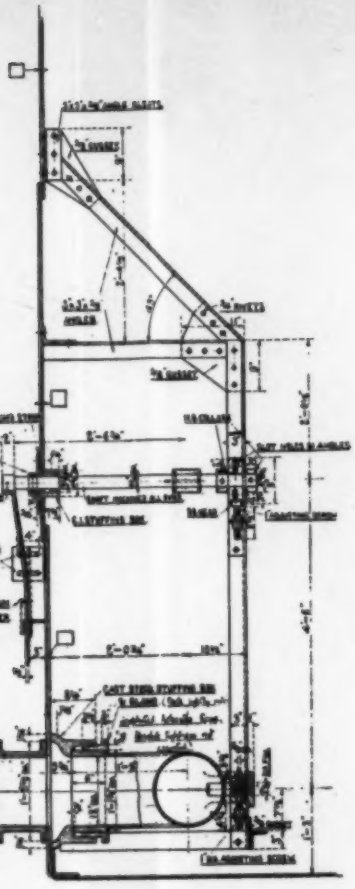
Fig. 4.

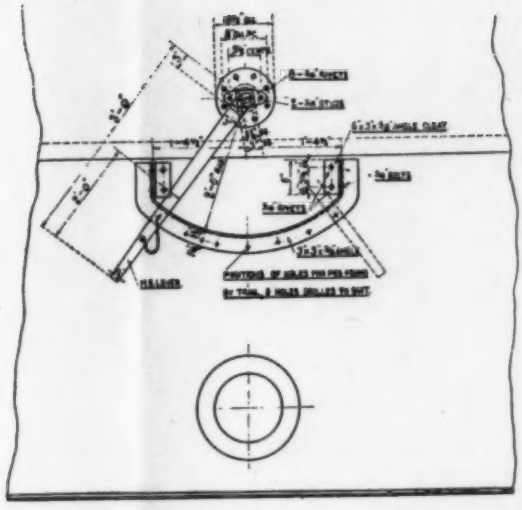


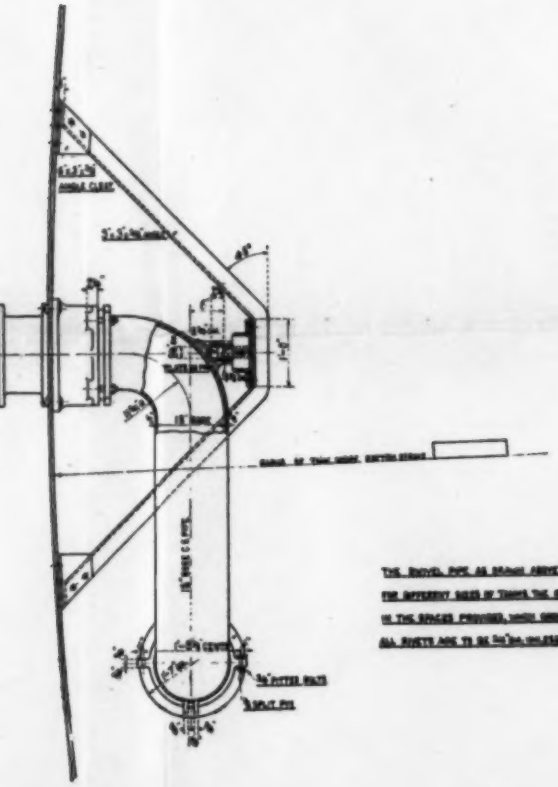








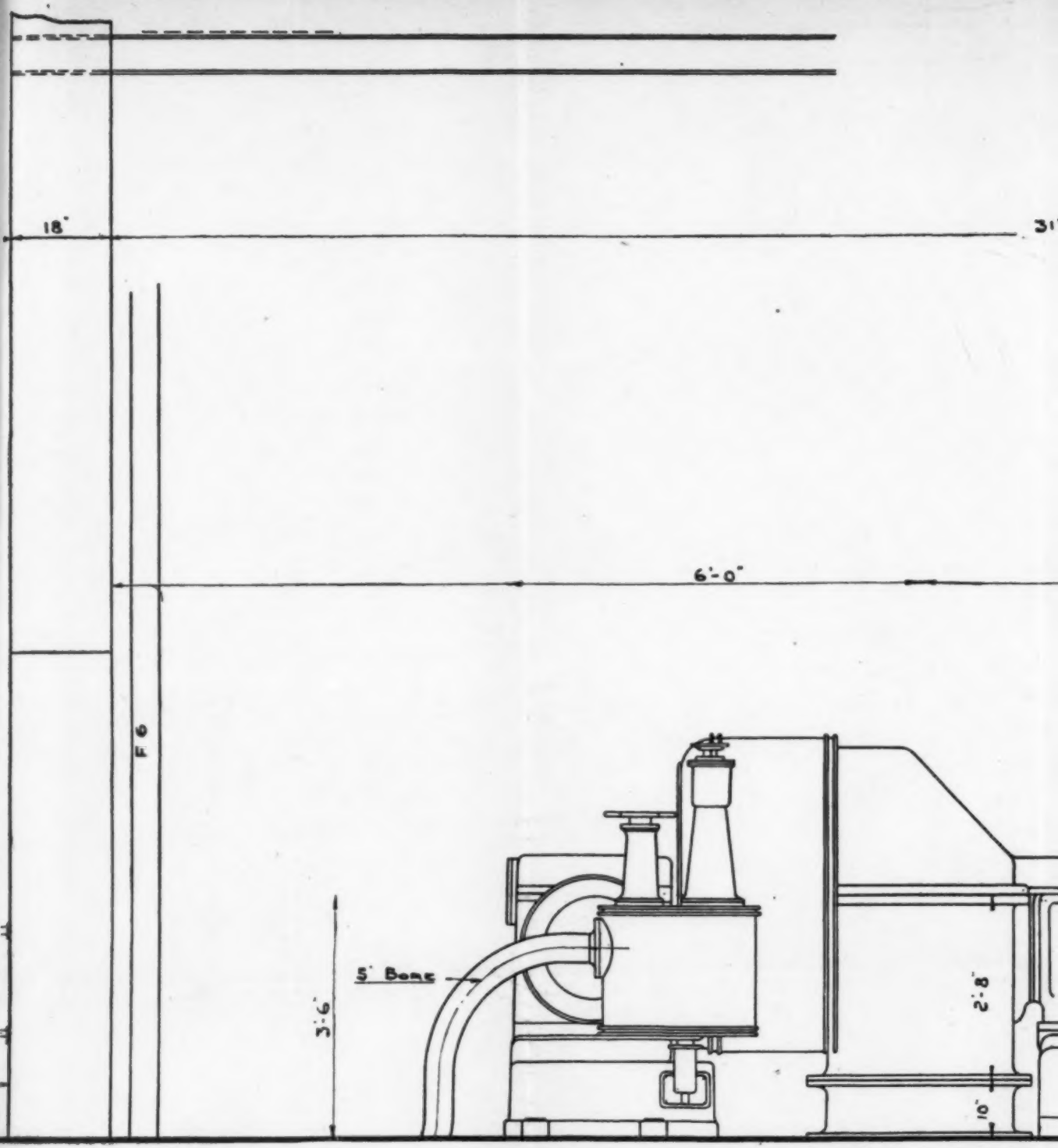




NOTE.

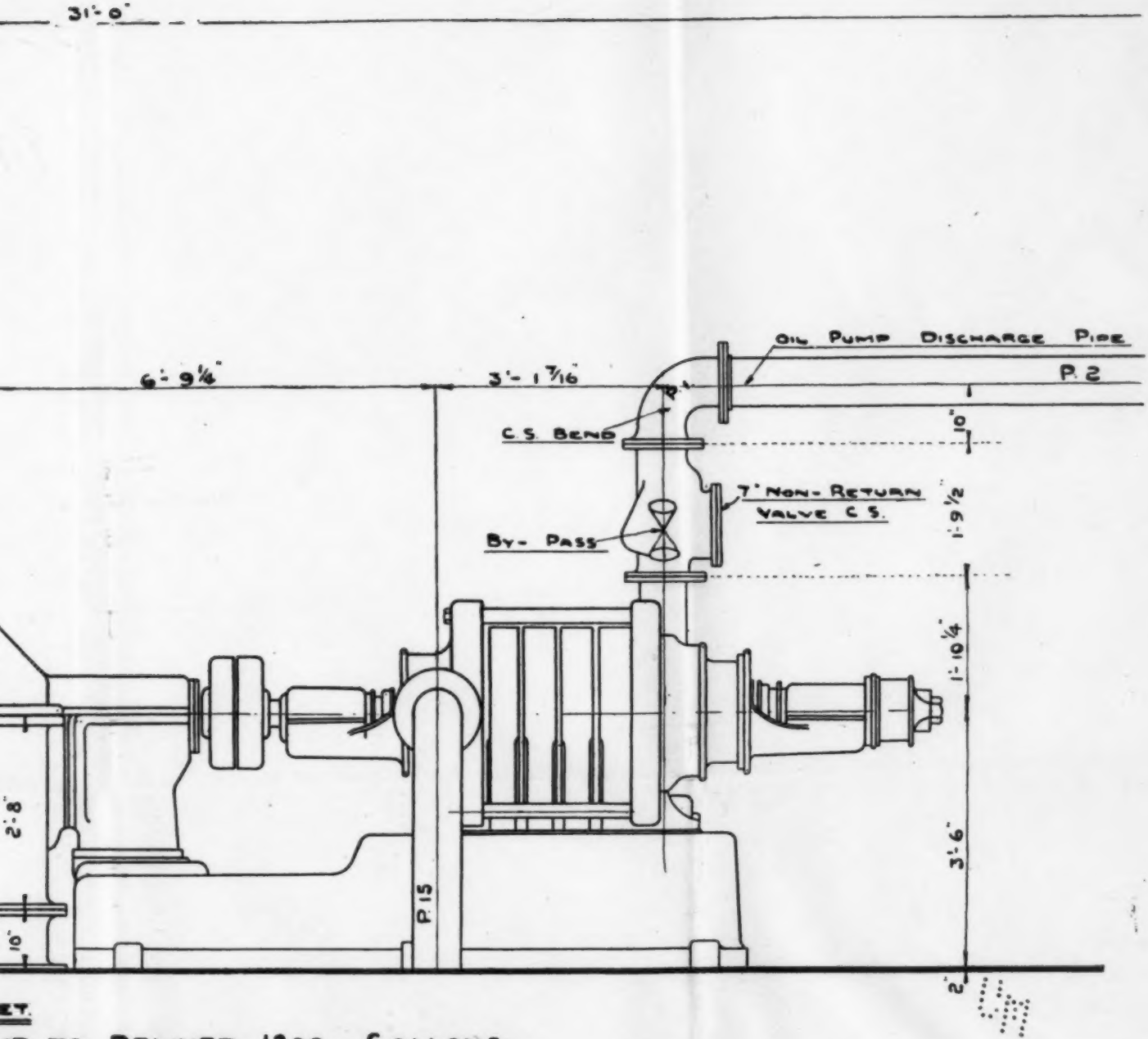
THE BOLTED PIPE AS SHOWN ABOVE IS SHOWN FITTED IN 96'-0"DIA x 64'-0" DEEP TANK TO SCALE.
FOR DIFFERENT SIZES OF TANKS THE GAUGE & THE THICKNESS OF PLATES ARE TO BE ENTERED IN
IN THE SPACES PROVIDED WHEN ORDERING.
ALL RIVETS ARE TO BE 5/8"DIA. UNLESS OTHERWISE STATED.

Fig. 5.



TURBO PUMPING SET.

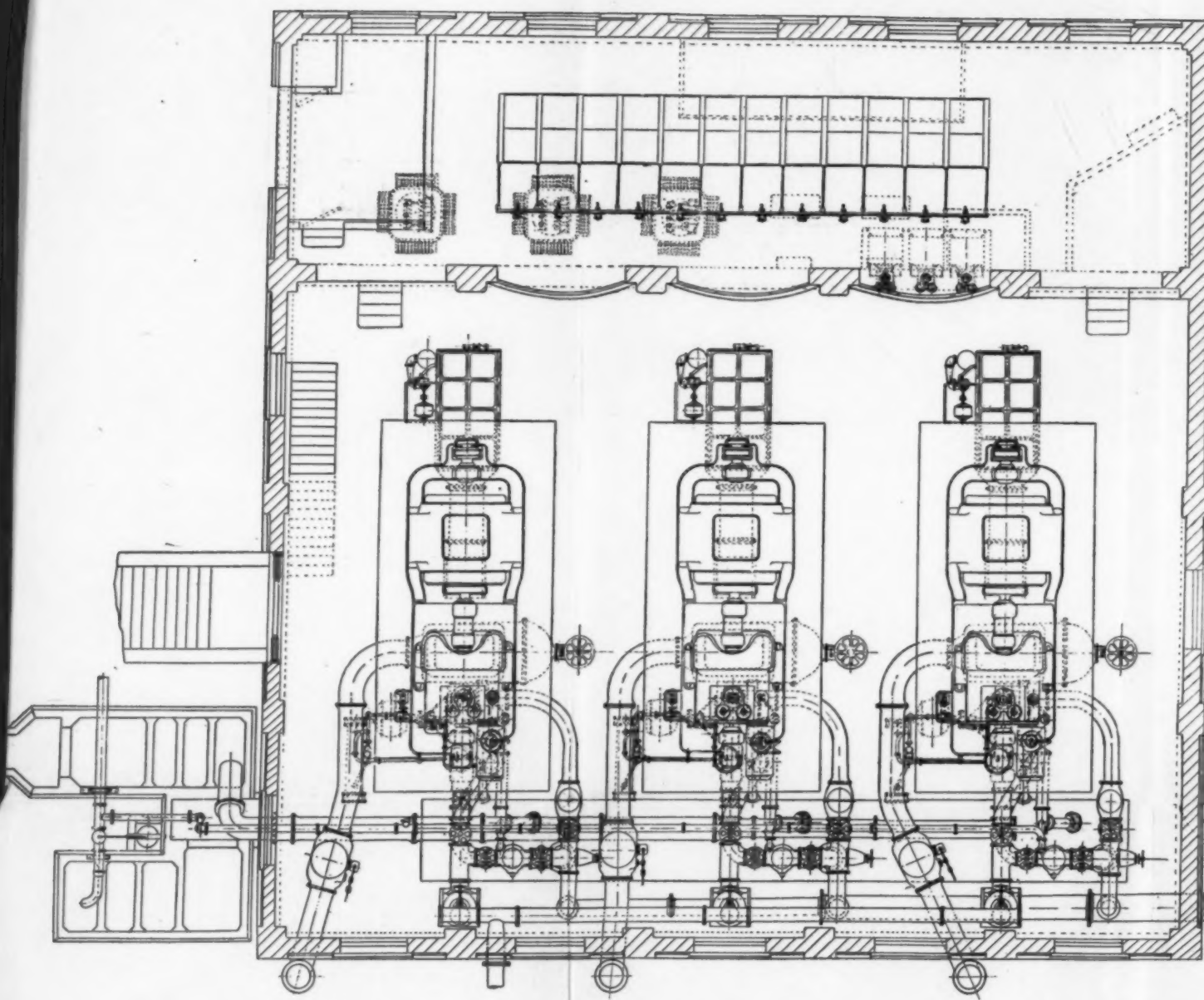
HIGH LIFT CENTRIFUGAL PUMP TO
OF CRUDE OIL PER MINUTE AGAINST
SQUARE INCH DRIVEN BY 800/1000
AT 1600/2100 R.P.M.

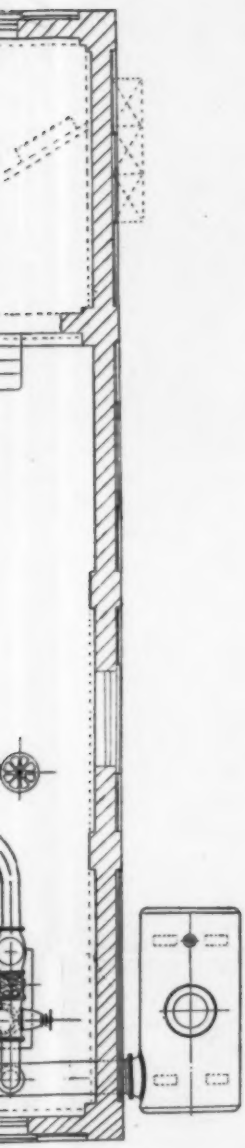


ET.

MP TO DELIVER 1300 GALLONS
GAINST A HEAD OF 600 LBS PER
0/1000 B.H.P. HIGH PRESSURE IMPULSE TURBINE
P.M.

Fig. 6.





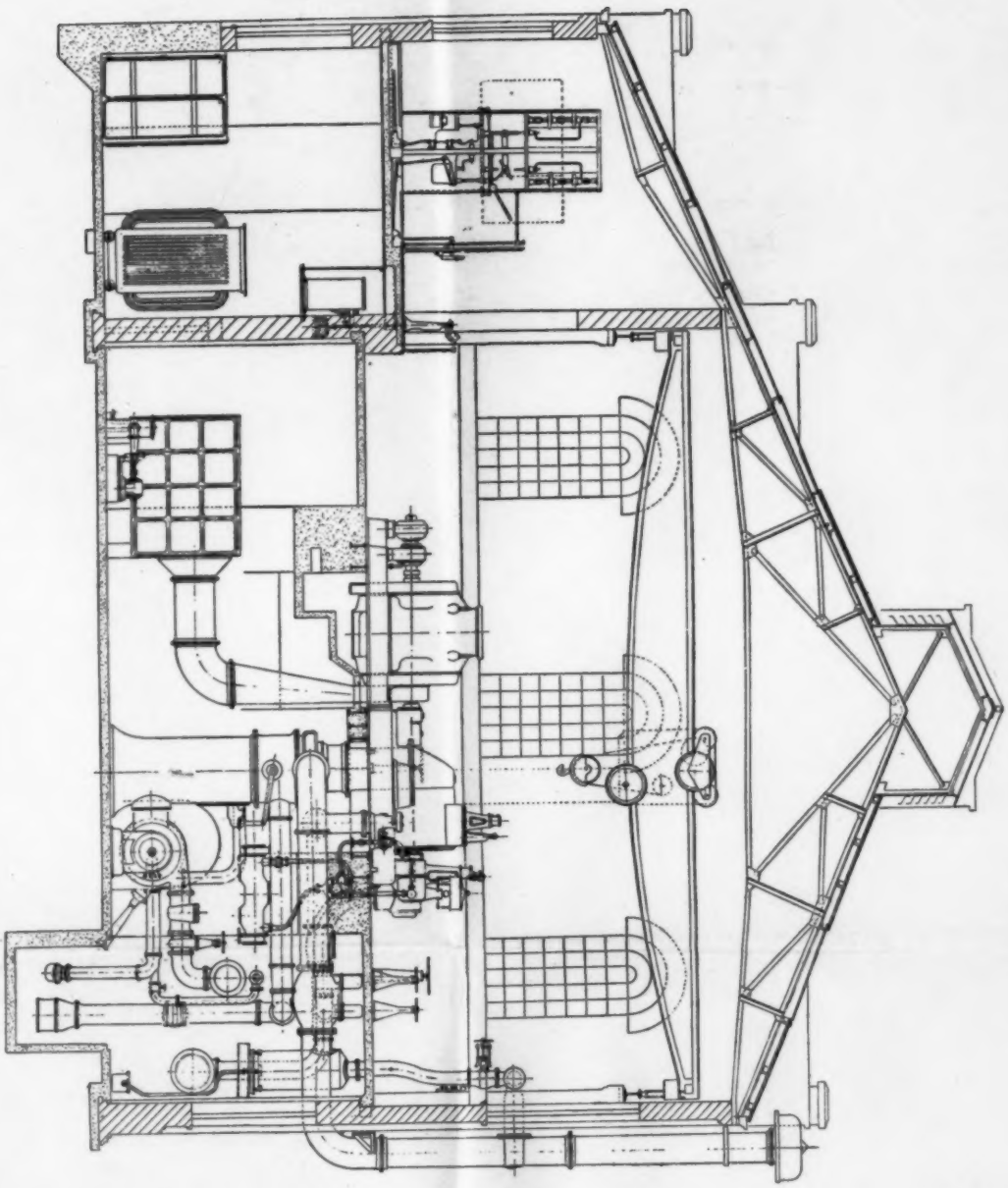
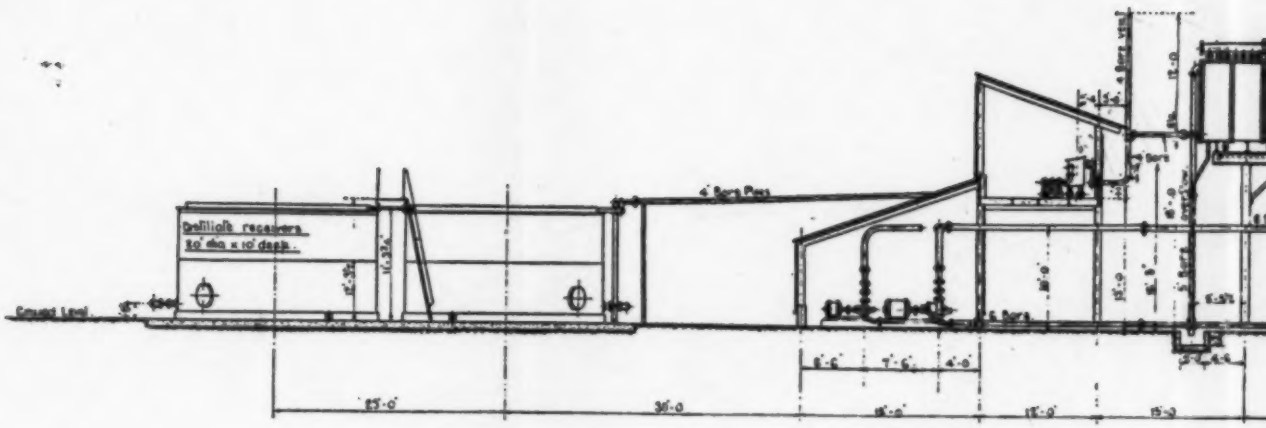
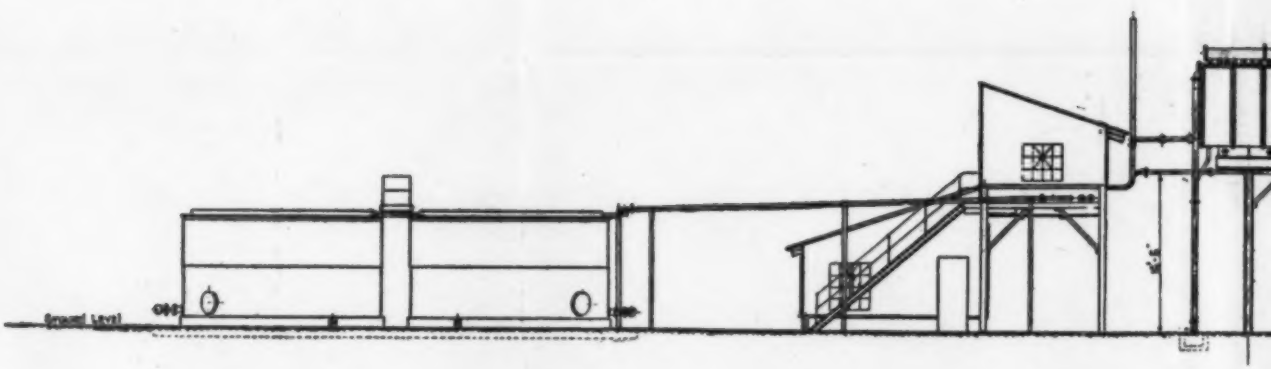


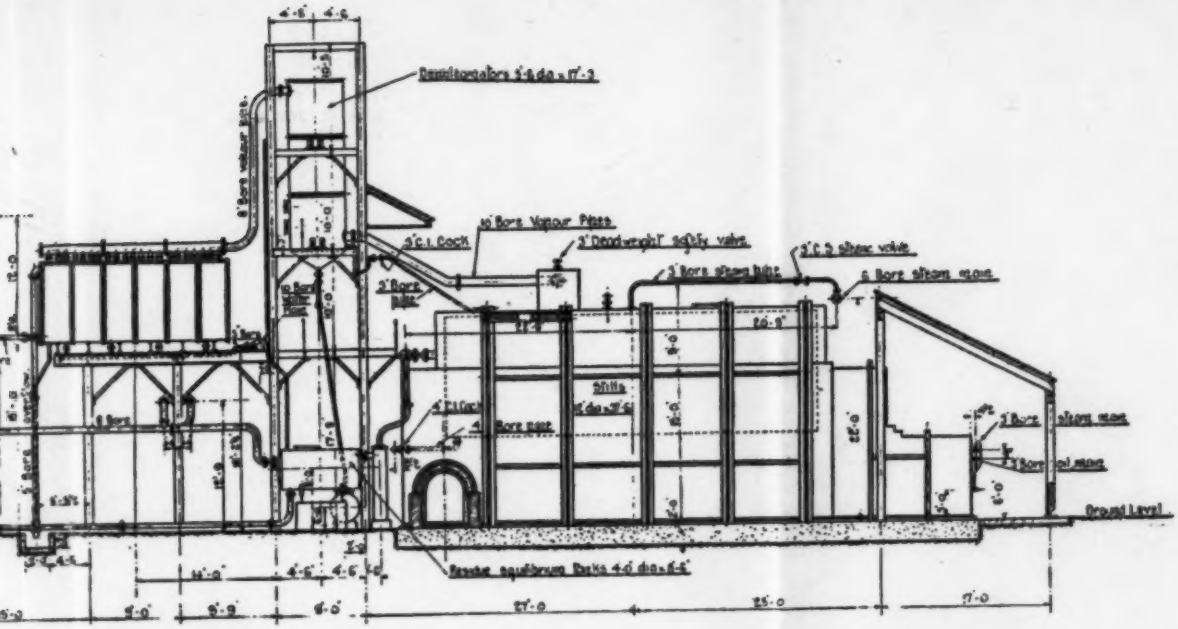
Fig. 8.



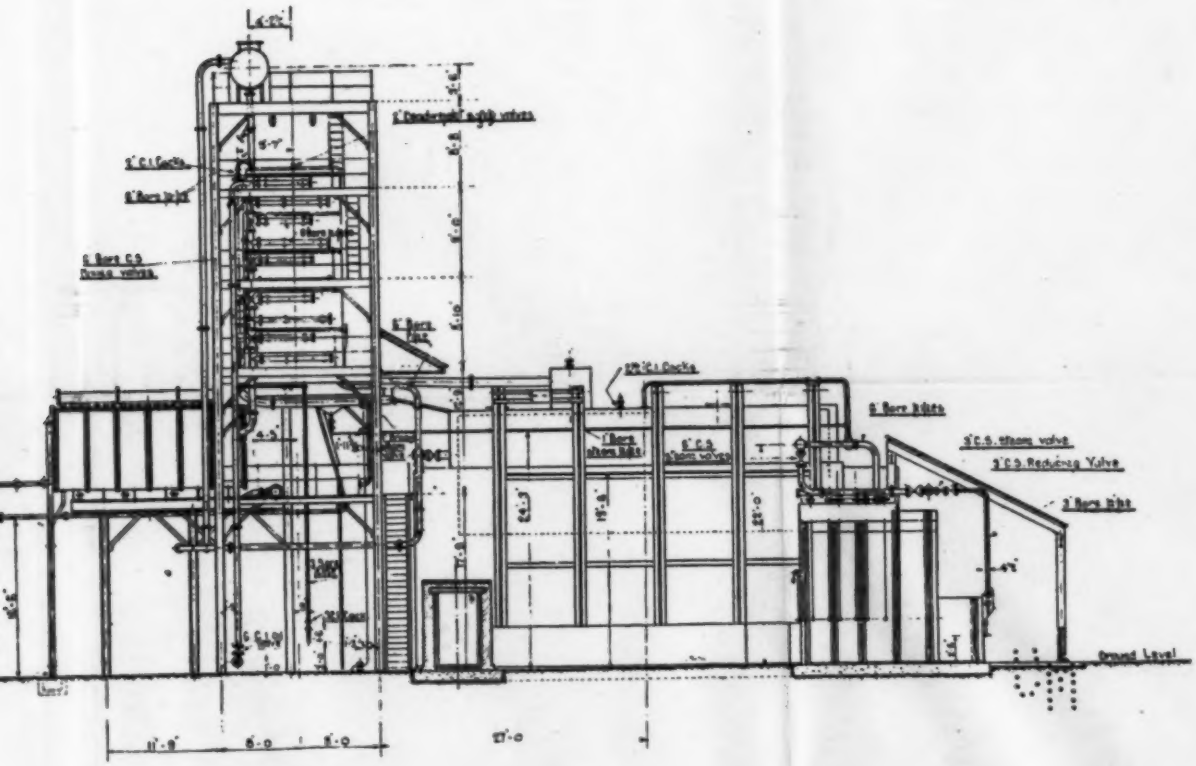
CROSS SEC



SIDE EL

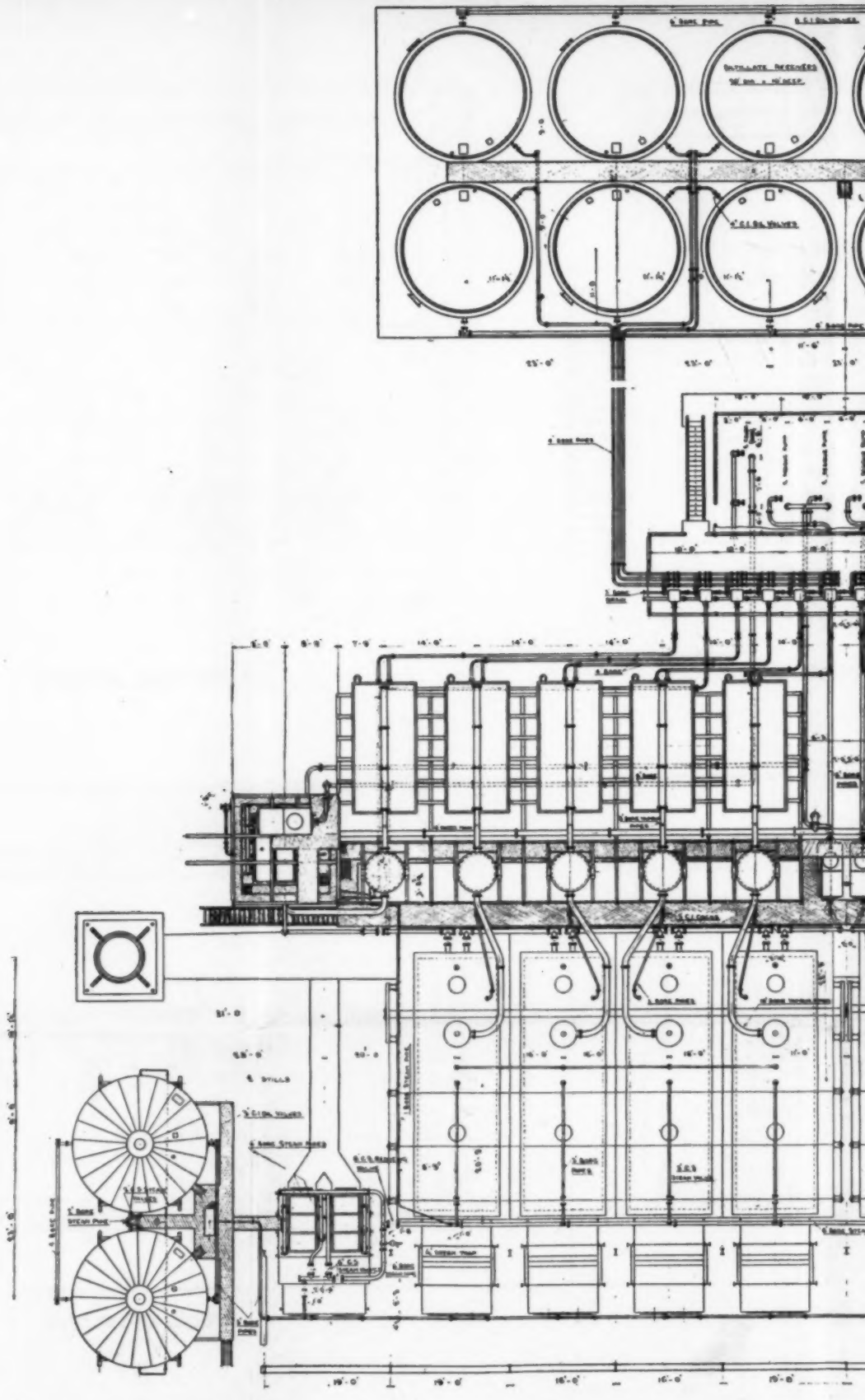


CROSS SECTION THRO ℄ OF BENCH



SIDE ELEVATION

Fig. 10.



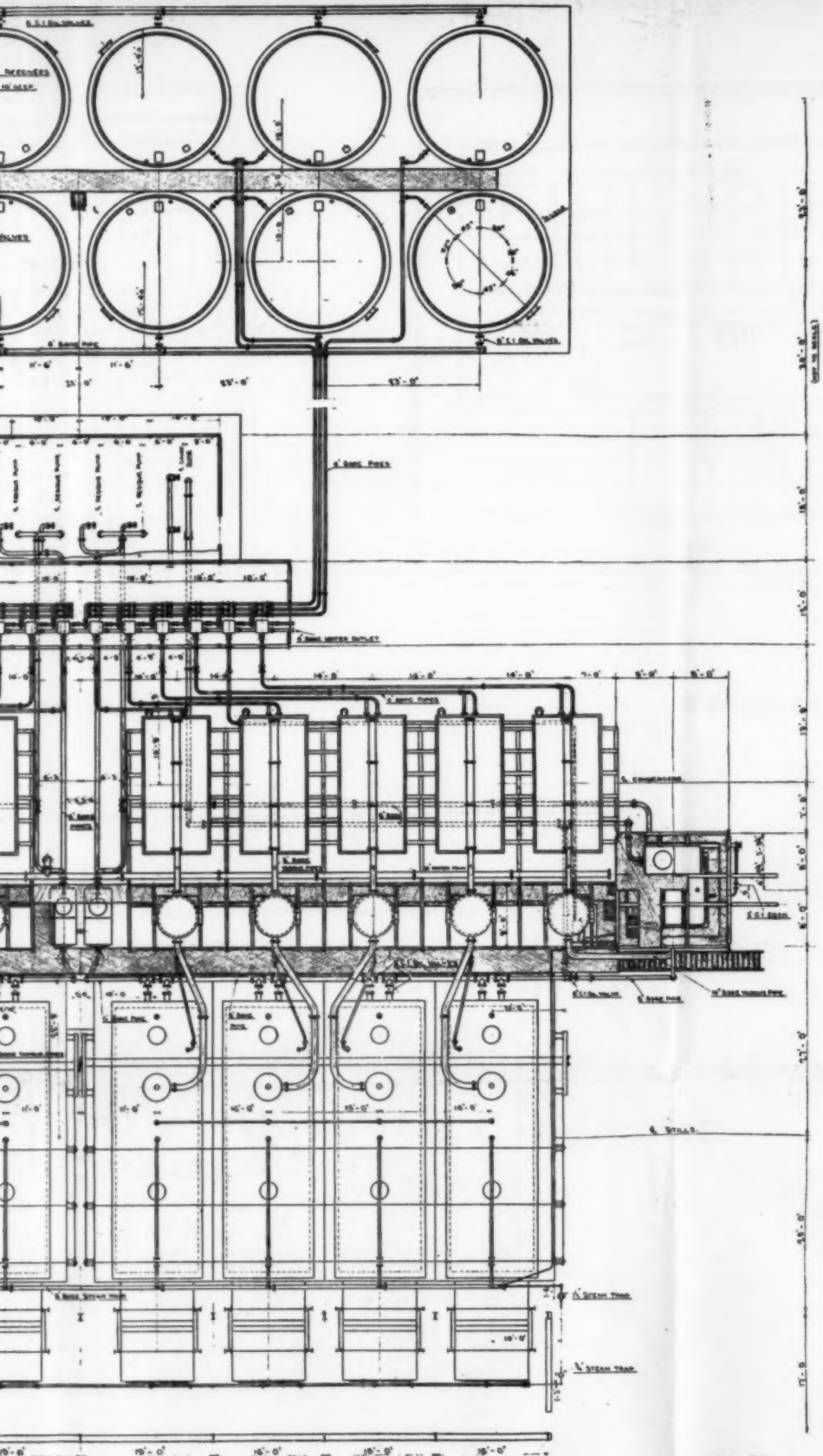
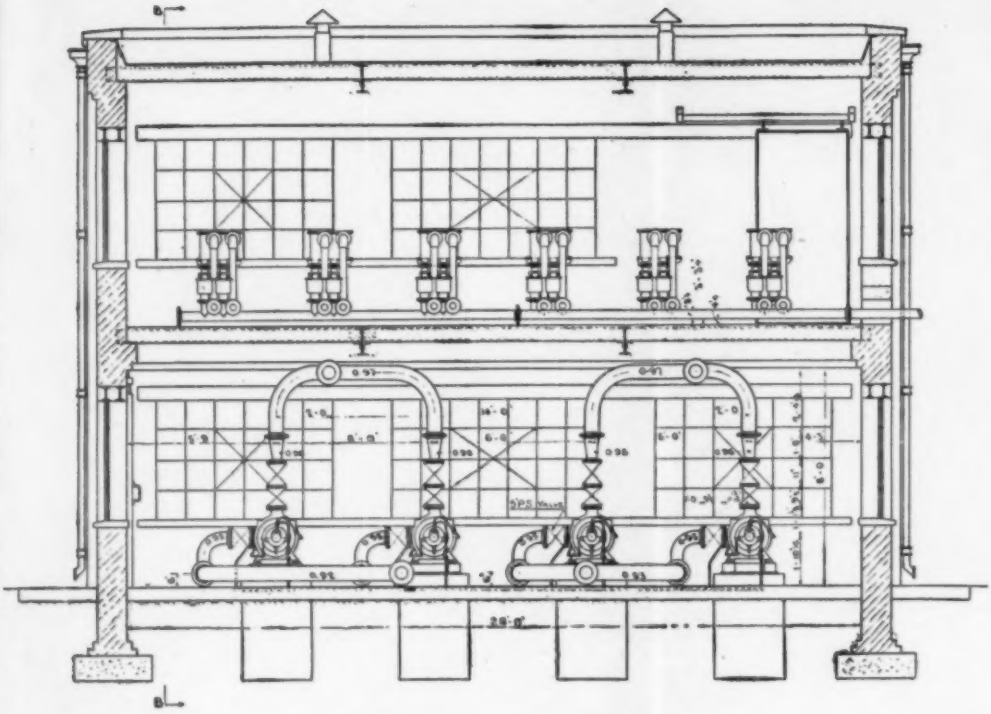
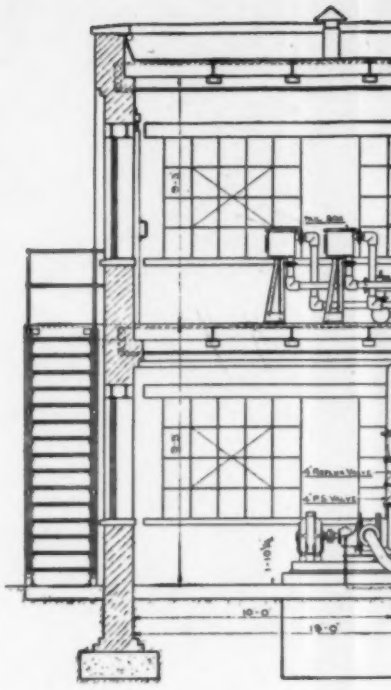


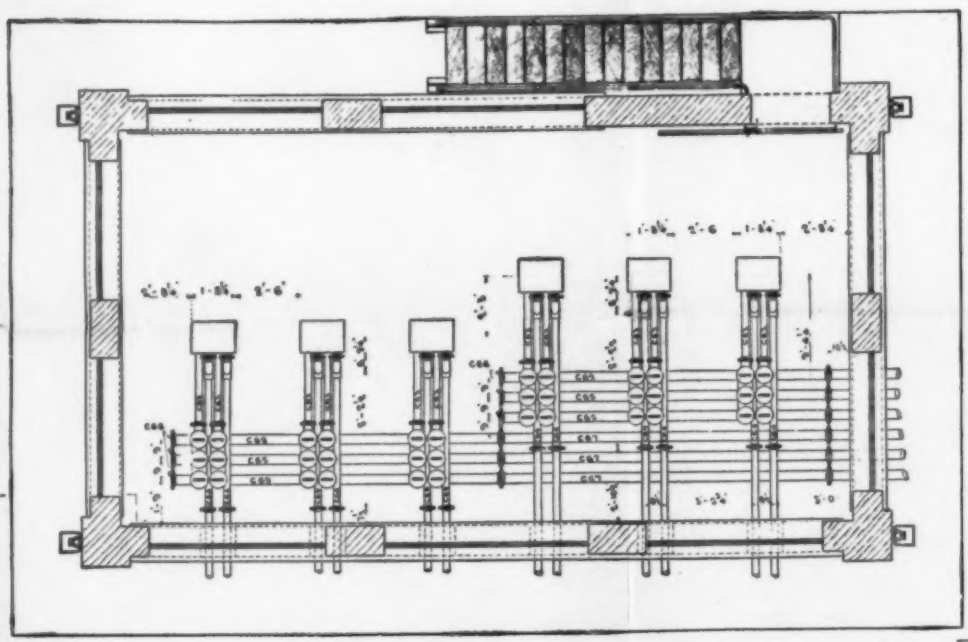
Fig. 11.



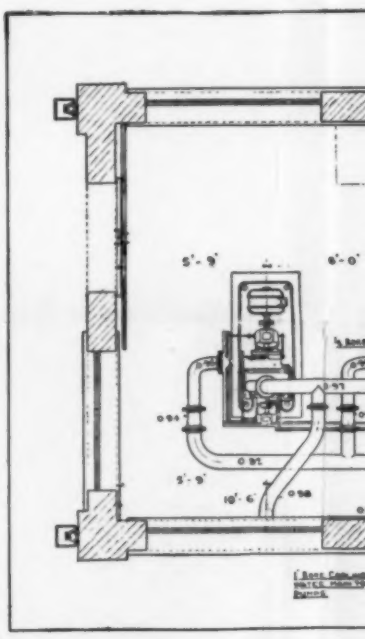
SECTIONAL ELEVATION "A.A."



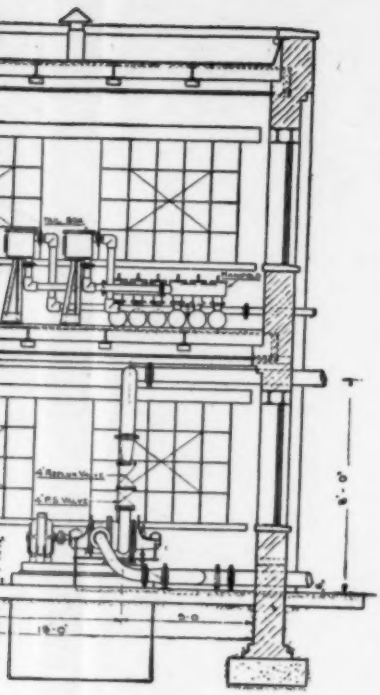
END ELEVATIO



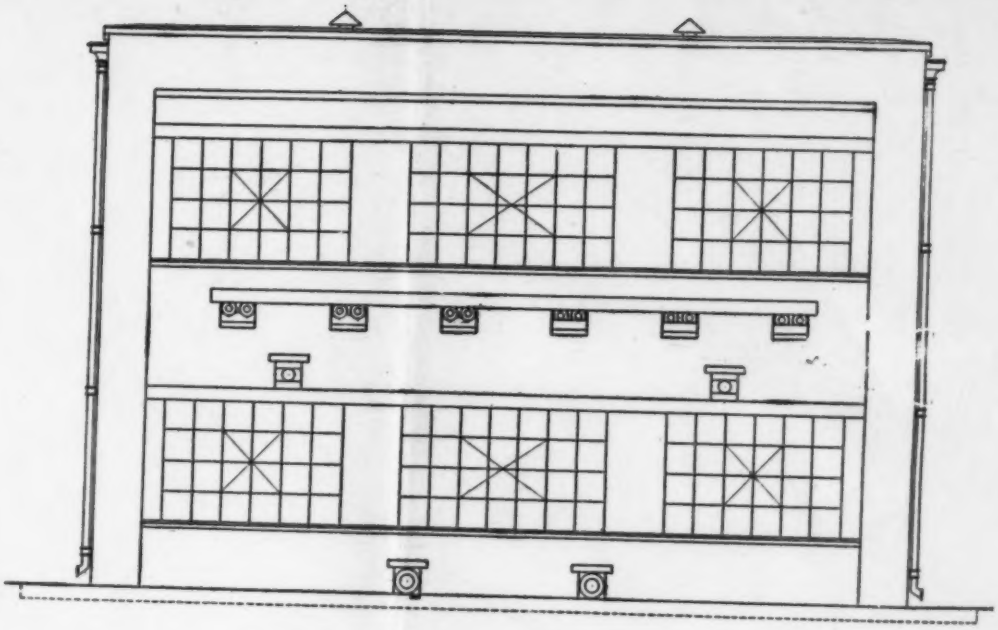
PLAN OF TAIL HOUSE.



PLA



ELEVATION "B B".



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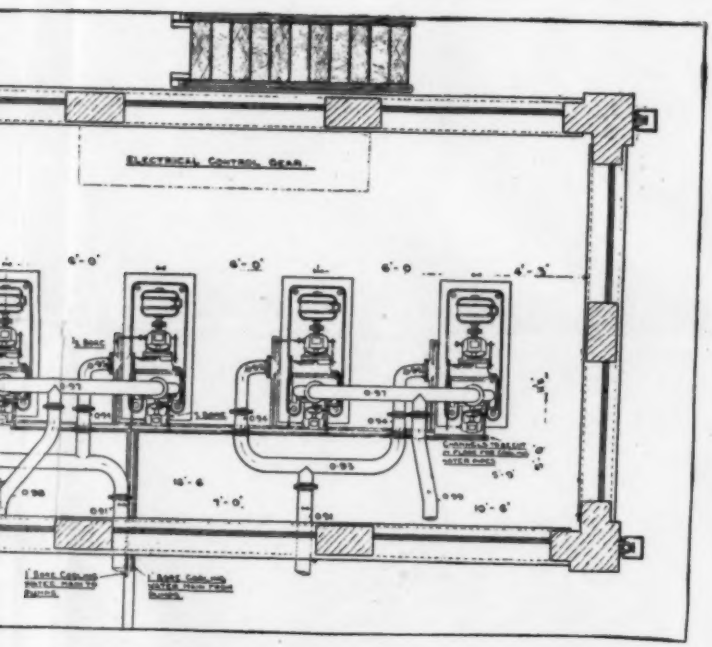
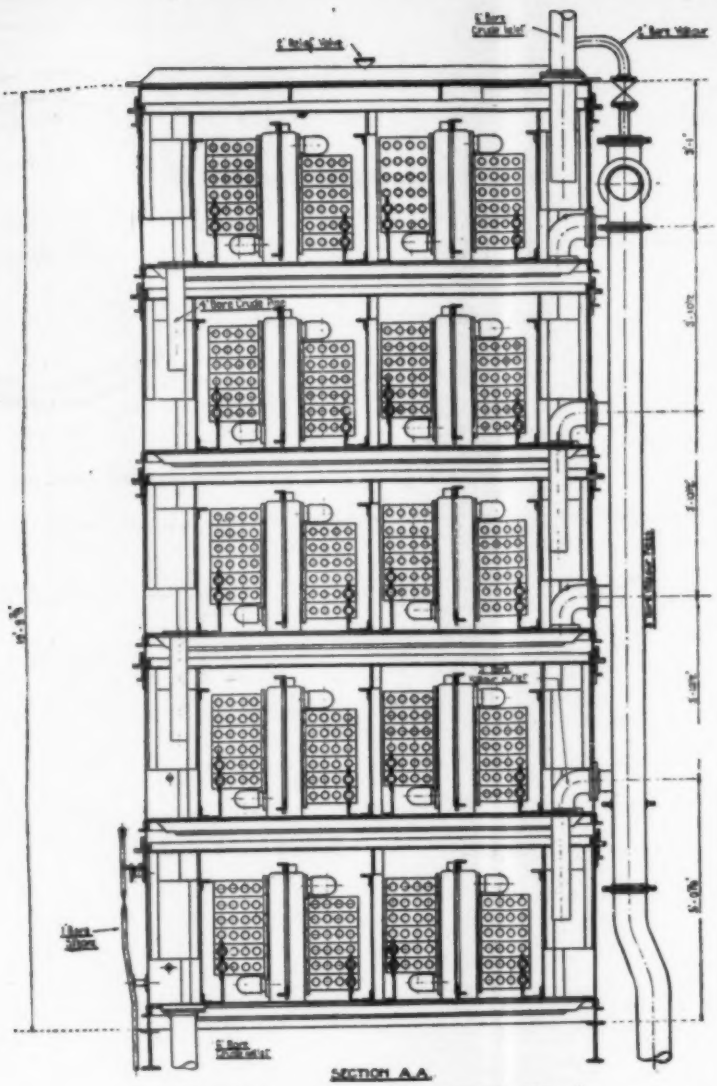
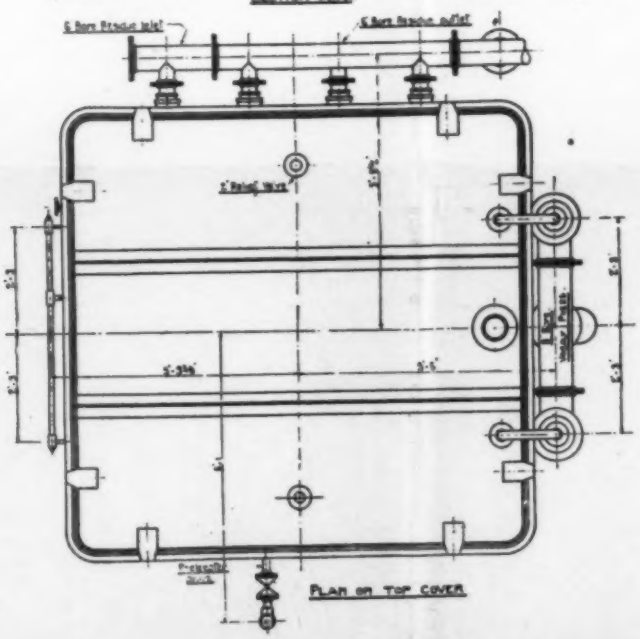


PLAN OF PUMP HOUSE.

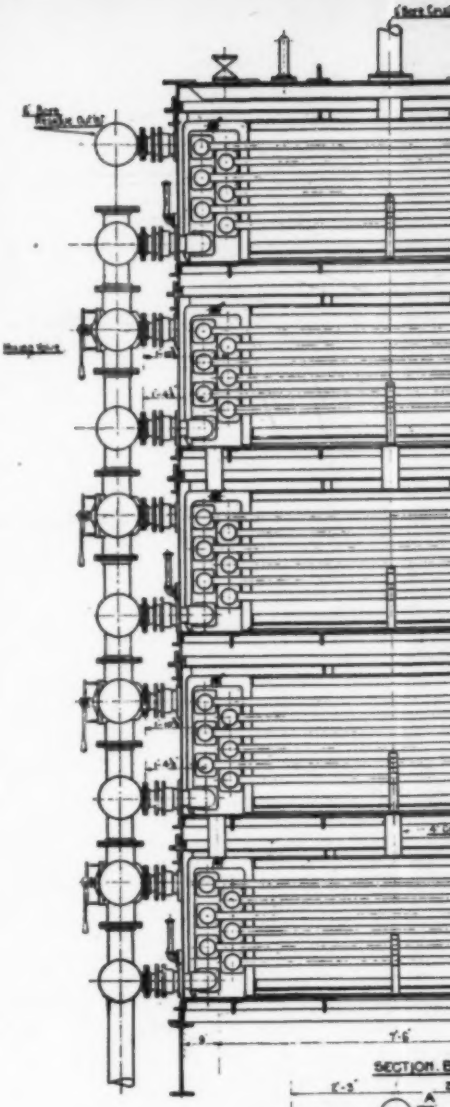
Fig. 13.

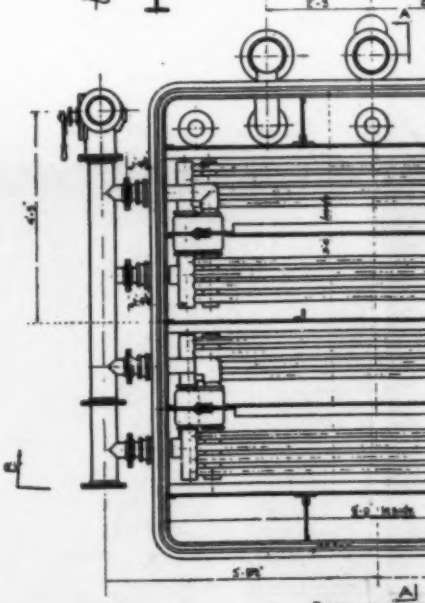


SECTION A.A.

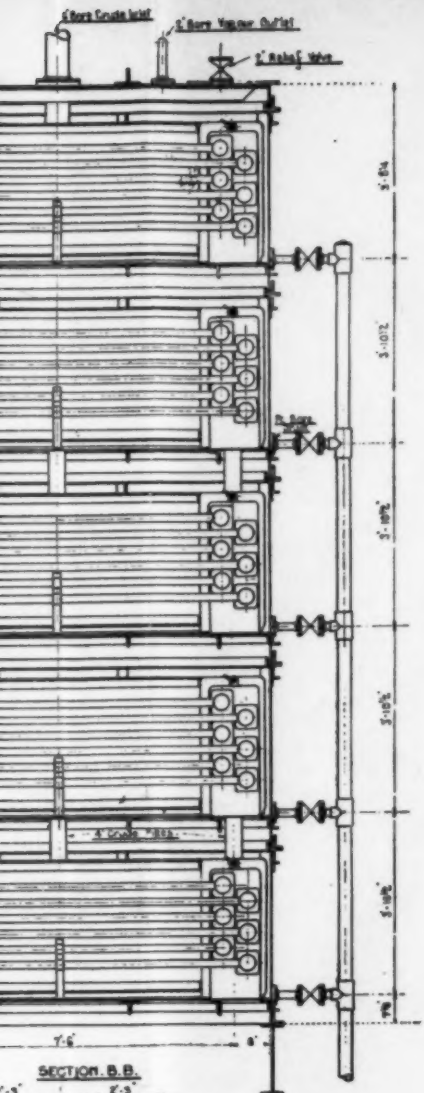


PLAN ON TOP COVER





PLAN OF SEC


SECTION B.B.
PLAN OF SECTION 2.

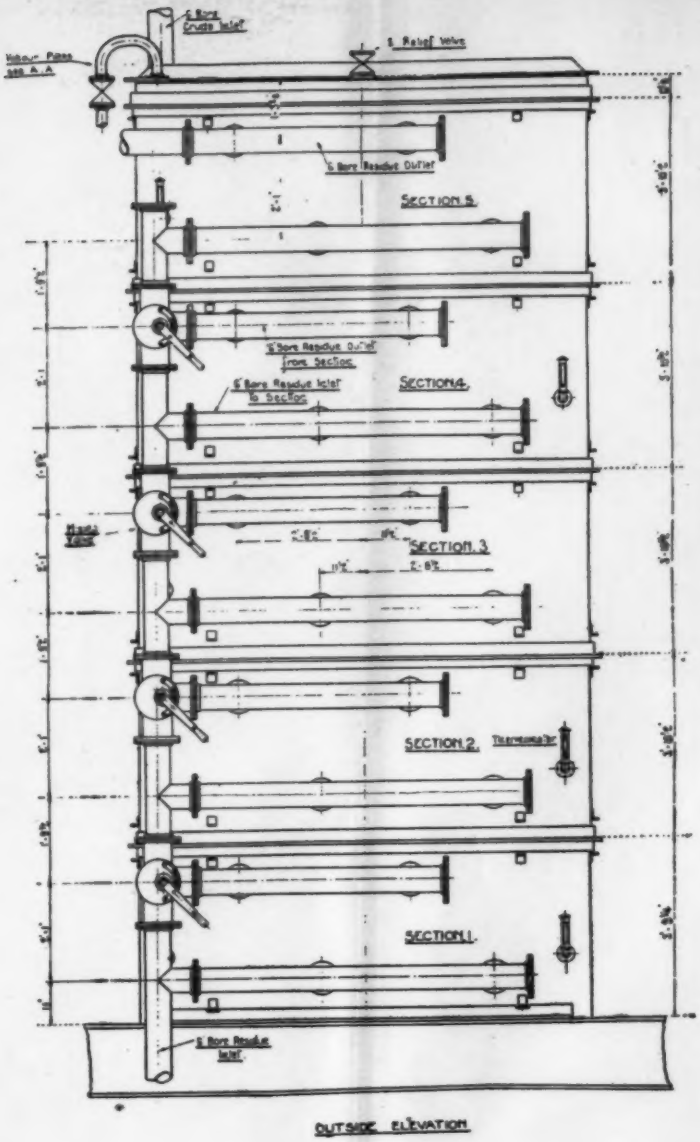
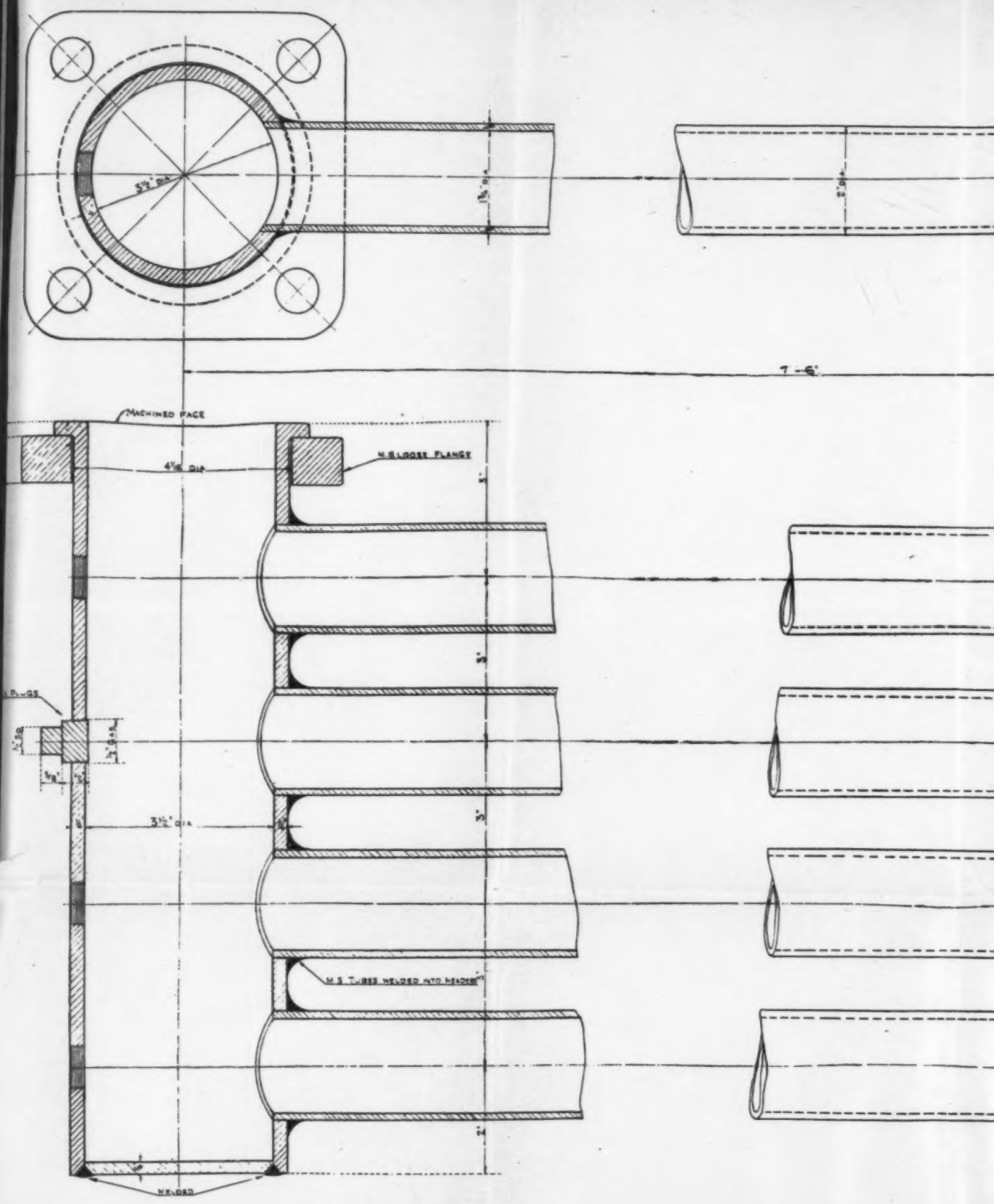

SECTION 5.
SECTION 4.
SECTION 3.
SECTION 2.
SECTION 1.
OUTSIDE ELEVATION

Fig. 14.


MACHINED FACE
4⅝" DIA
M.S LOOSE FLANGE
3½" DIA
M.S TUBES WELDED INTO HEADER
WELDED
7'-6"

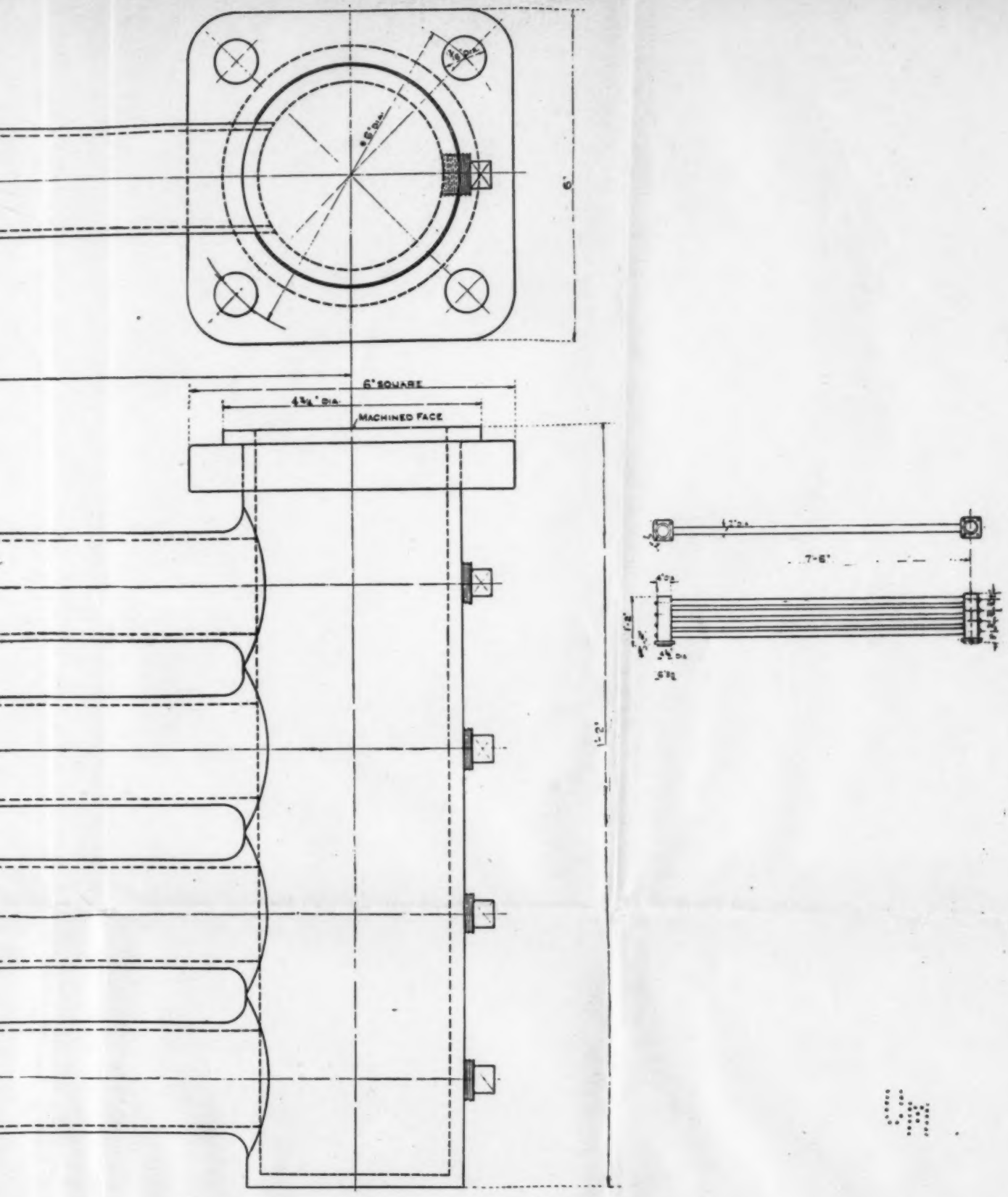
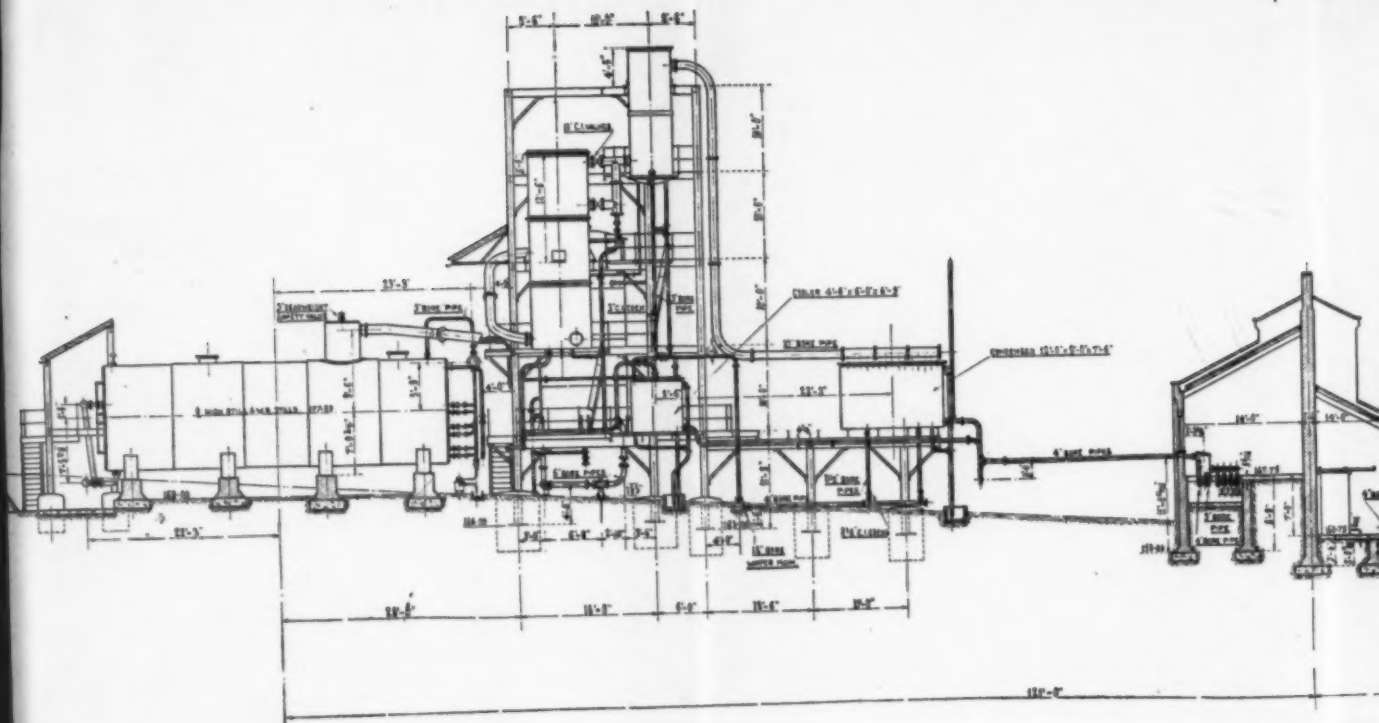
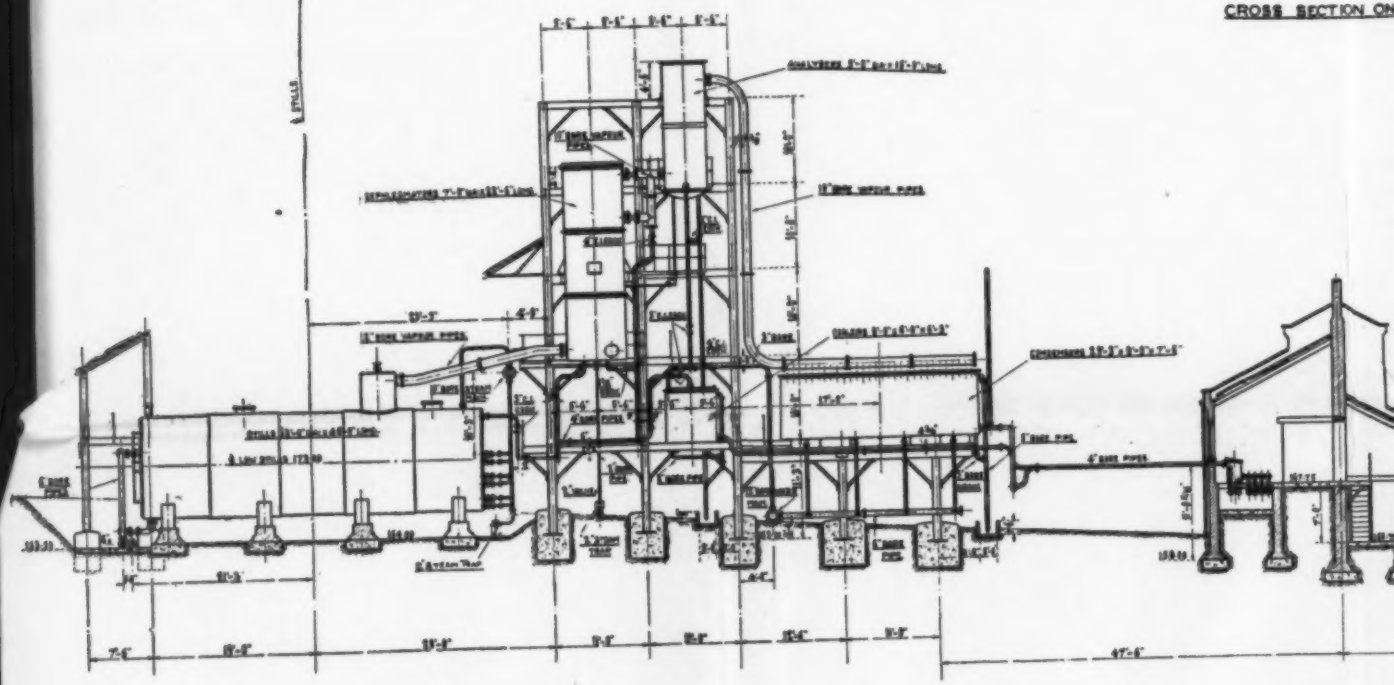


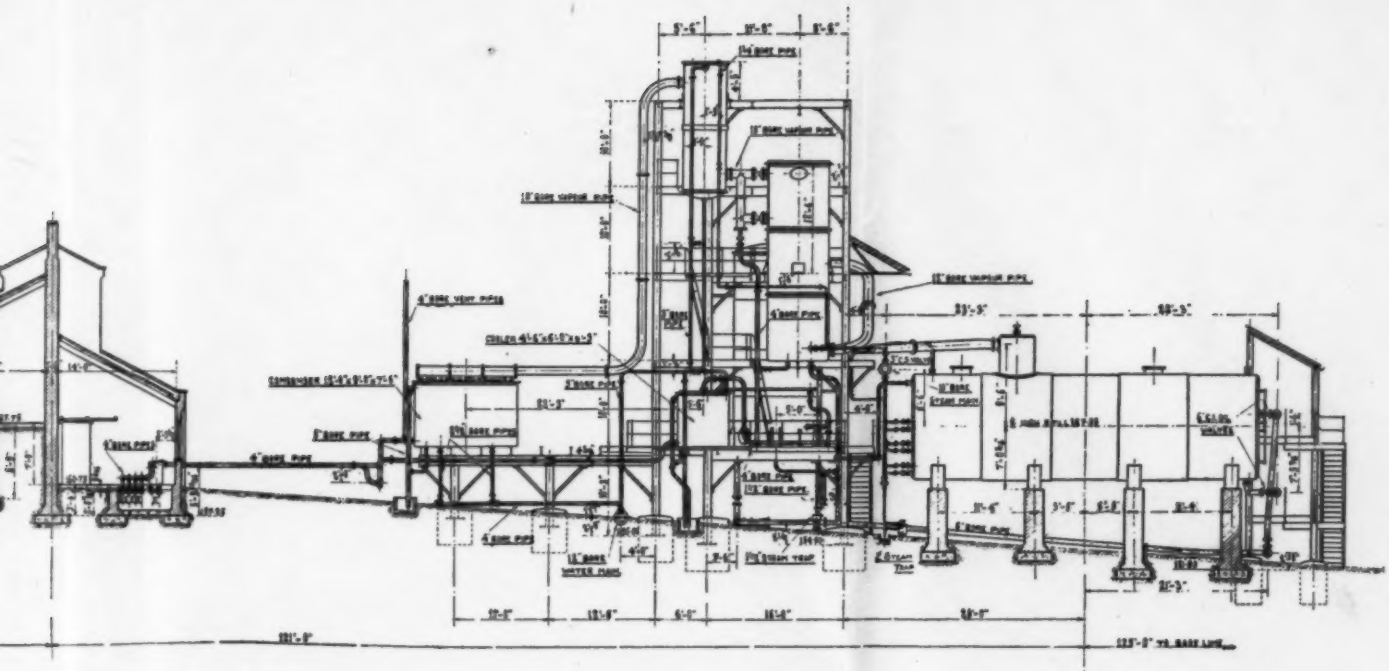
Fig. 15.



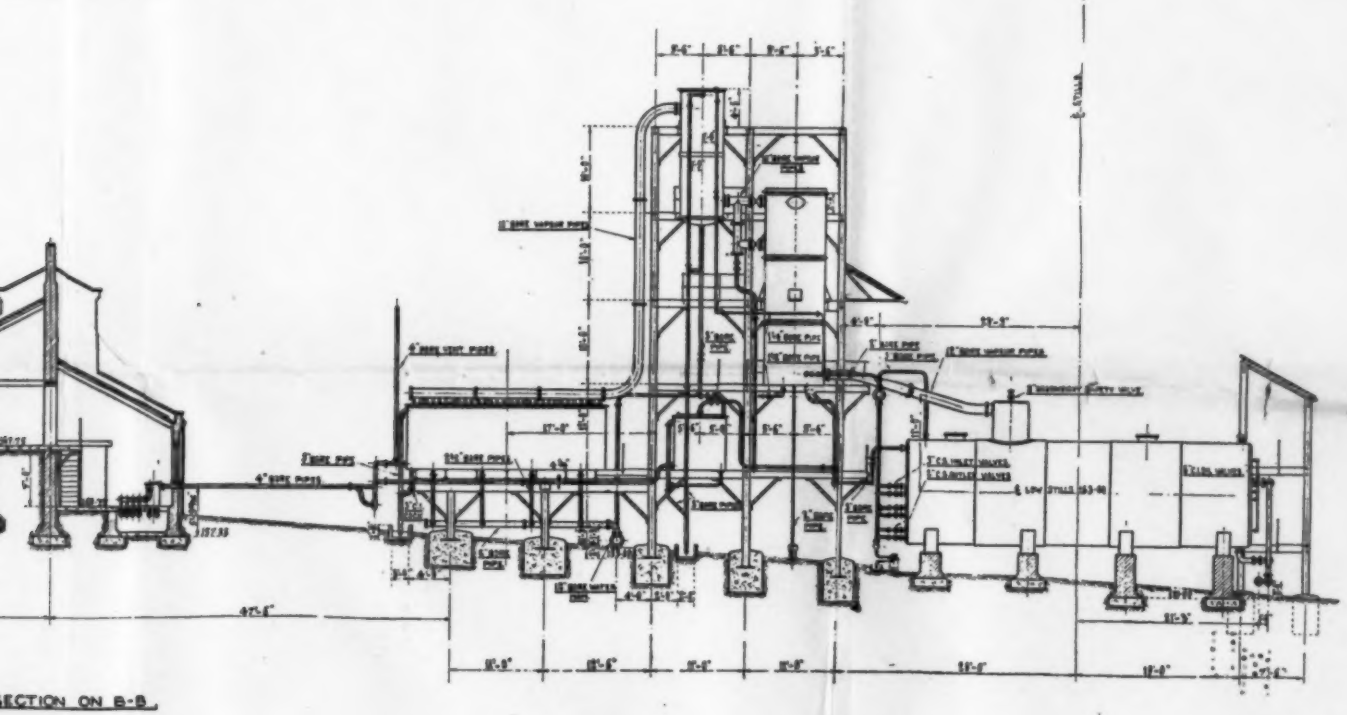
CROSS SECTION ON



CROSS SECTION ON

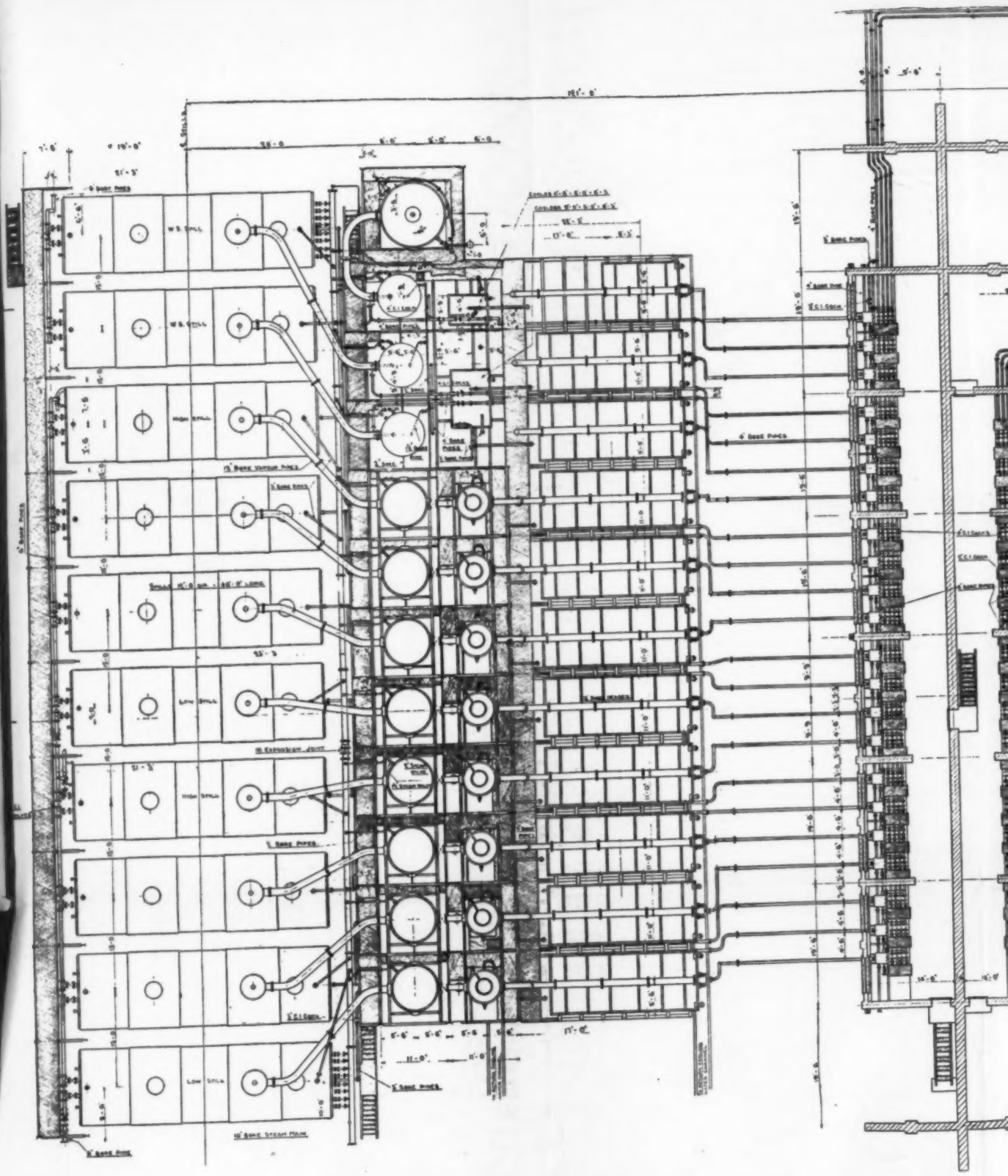


SECTION ON A-A.



SECTION ON B-B.

Fig. 16.



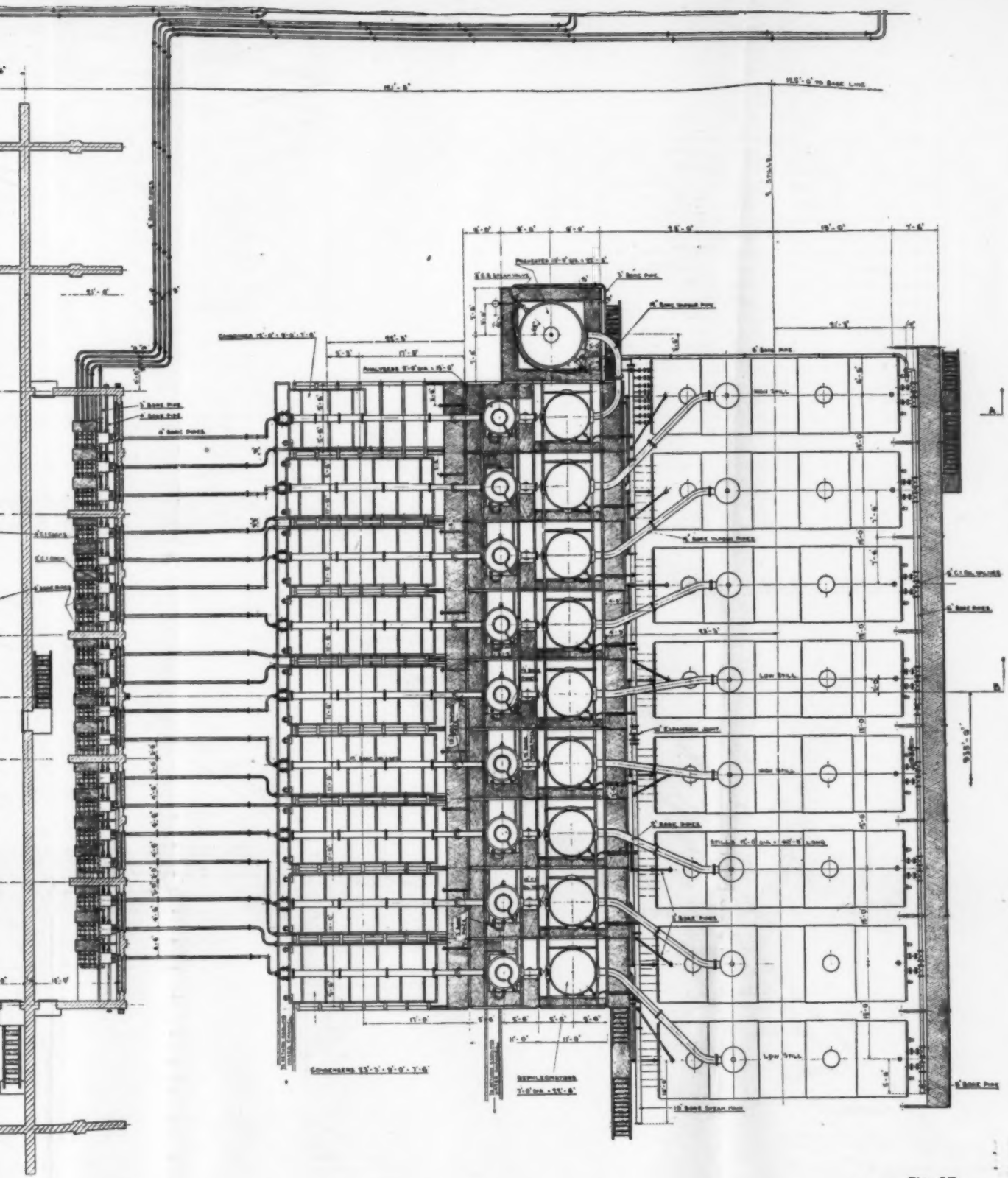
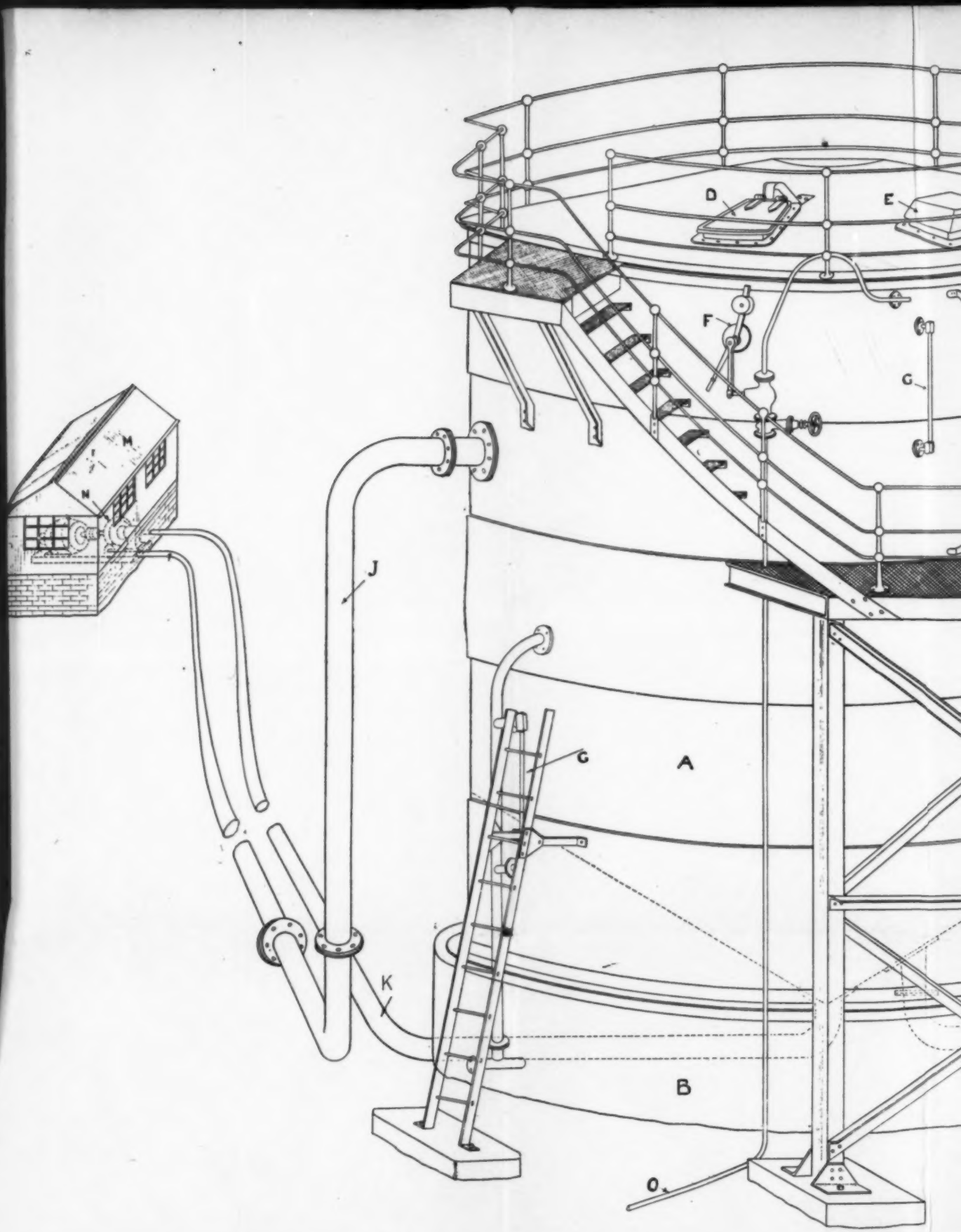


Fig. 17.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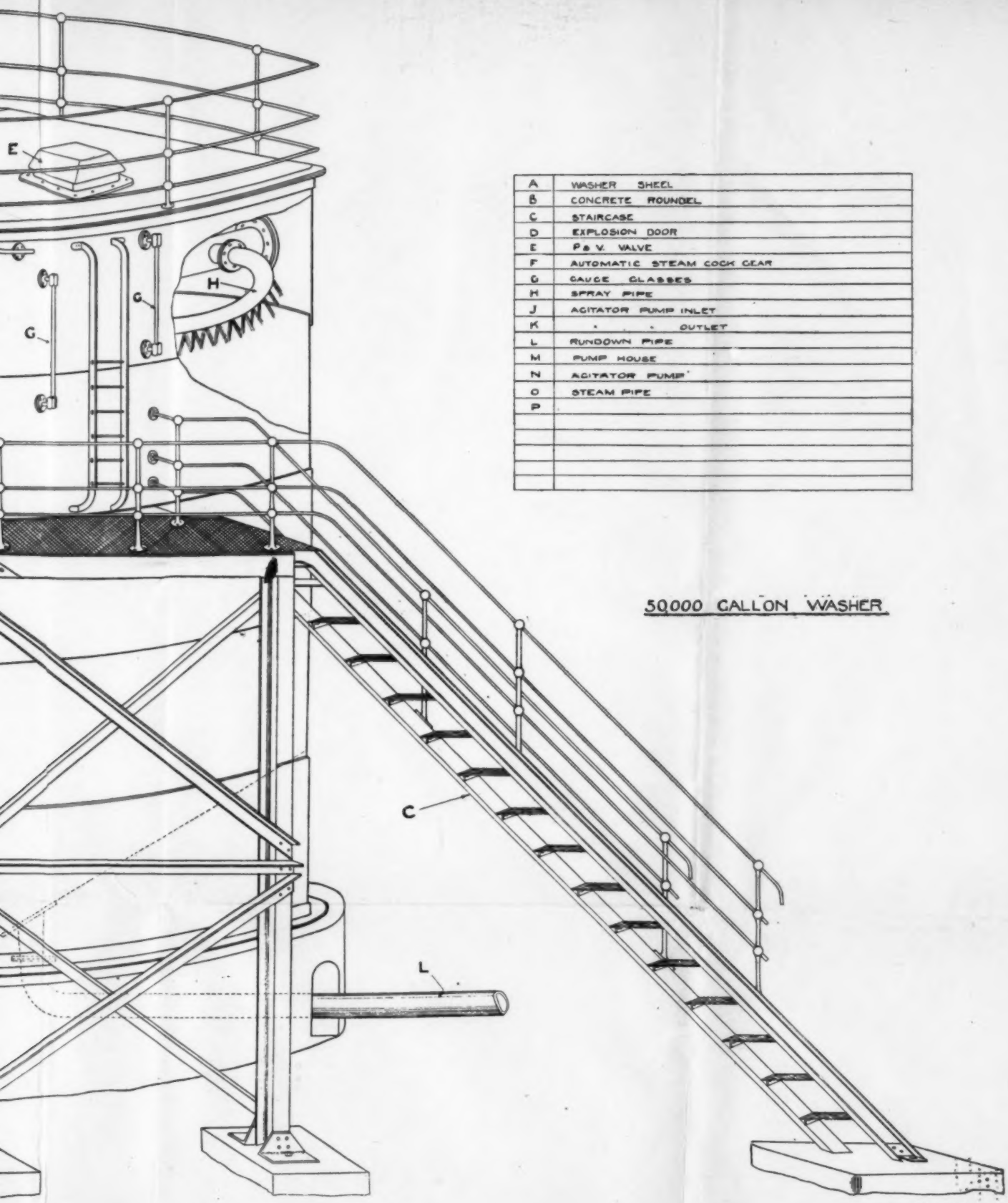


A	WASHER SHEEL
B	CONCRETE ROUNDEL
C	STAIRCASE
D	EXPLOSION DOOR
E	P & V. VALVE
F	AUTOMATIC STEAM COCK GEAR
G	GAUGE GLASSES
H	SPRAY PIPE
J	AGITATOR PUMP INLET
K	" " OUTLET
L	RUNDOWN PIPE
M	PUMP HOUSE
N	AGITATOR PUMP
O	STEAM PIPE
P	

50,000 GALLON WASHER

Fig. 18.

a question of h.p. hours. In one case a 5 h.p. pump was doing what would have required with mechanical agitation 50 h.p., and the h.p. hours were much lower. The thermal efficiency mentioned was the ratio of the B.Th.U.'s put into the boiler-house and those absolutely applied in the refinery—not the efficiency of the turbines or condensing plant or the boiler efficiency. Out of every 100 B.Th.U.'s put into the boiler-house in the shape of fuel 50 were employed in the refinery, either as electricity or as steam. The heat balance, functioning as an ordinary turbo-generator, or as a reducing turbine, is shown diagrammatically in Fig. 19.

The Chairman (Mr. Ashley Carter) said that he was sure it was the wish of the members that a very hearty vote of thanks should be accorded to Mr. Dalley for his exceedingly valuable contribution to the proceedings of the Congress.

Thursday, June 5th, 1924, *at* 10.30 *a.m.*

W. R. ORMANDY, D.Sc., F.I.C., F.C.S., M.I.A.E., Member of Council of the Institution of Petroleum Technologists, in the Chair.

The Chairman, after apologising for the absence of Mr. Herbert Barringer, the President of the Institution of Petroleum Technologists, who was unable to be present to take the Chair at the meeting, said he did not think it was necessary for him to introduce the reader of the paper, Dr. A. E. Dunstan, who was well known to everybody connected with the oil industry. He was sure they would all listen with very great interest to a paper dealing with a type of material which was so difficult to obtain, but which was so valuable to those who were engaged in the oil industry.

Crude Oils of the Empire.

By A. E. DUNSTAN, D.Sc., F.I.C., F.C.S., Member of the Councils of the Chemical Society and of the Institution of Petroleum Technologists; and

JAMES KEWLEY, M.A., F.I.C., F.C.S., Member of the Council of the Institution of Petroleum Technologists.

IN collecting the following account of the crude oils of the Empire the authors feel very acutely the paucity of the material at their disposal. In lamentably few cases have any mineral oils received adequate scientific attention, and little is known of the vast majority except scanty data, chiefly relating to physical constants. On several previous occasions the authors have drawn attention to the lack of investigation into the nature, the origin and the metamorphoses of crude oils.

In the first place it should be noticed that the oil resources of the Empire are very small compared with those of the United States. Table 1 (From Petroleum and Allied Products—Mineral Industry of the British Empire and Foreign Countries, Imperial Mineral Resources Bureau, London, 1924) indicates that 2 per cent. of the world's petroleum at the moment is Imperial in origin :—

TABLE 1.

World's Production of Petroleum (*including Shale Oil*).

(Long tons.)

British Empire—	1913.	1914.	1915.	1916.
United Kingdom..	290,000	285,000	263,000	247,000
Canada	32,583	30,686	30,781	28,303
Trinidad	70,506	90,092	147,015	132,554
India	1,132,878	1,058,541	1,171,811	1,213,019
Sarawak	19,953	45,039	55,460	90,570
Australia	5,435	16,016	4,952	5,576
New Zealand ..	444	412	556	560
Total British Empire	1,552,000	1,526,000	1,674,000	1,718,000

British Empire—	1917.	1918.	1919.	1920.	1921.
United Kingdom	250,000	243,000	214,000	234,000	145,000
Canada ..	30,547	43,535	34,353	28,036	26,792
Trinidad ..	228,902	297,438	263,007	297,575	336,308
India	1,154,120	1,169,734	1,247,956	1,196,395	1,247,687
Sarawak ..	76,738	71,366	85,143	148,633	201,572
Australia ..	10,121	10,366	10,000[2]	8,000[2]	10,500[2]
New Zealand ..	600[2]	600[2]	500[2]	400[2]	400[2]
Total British Empire ..	1,751,000	1,836,000	1,855,000	1,913,000	1,968,000

Foreign Countries—	1913.	1914.	1915.	1916	1917.
Austria ..	1,095,800	862,900	666,063	912,535	915,440
France[1] ..	5,000[2]	9,888	3,961	5,796	6,768
Germany[3] ..	119,055	108,400	97,700	91,200	89,100
Hungary ..	2,071	3,962	6,431	6,000[2]	8,966
Italy	6,466	5,455	6,008	6,936	5,580
Poland (Galicia)	—	—	—	—	—
Rumania ..	1,818,177	1,781,078	1,562,803	884,546	712,591
Russia	8,976,337	9,574,360	9,792,580	9,711,000	8,429,000
Egypt	12,581	98,078	29,571	56,815	134,646
Mexico	3,773,629	3,852,801	4,833,073	5,962,203	8,131,447
United States ..	35,492,319	37,966,076	40,157,729	42,966,737	47,902,229
Argentina ..	18,849[4]	39,816[4]	74,169[4]	125,812	176,612
Peru	269,064	240,987	338,312	340,201	341,514
Venezuela ..	—	—	—	—	17,792
Dutch E. Indies	1,501,388	1,544,199	1,572,772	1,702,017	1,763,798
Formosa ..	2,582	2,469	2,706	2,848	1,965
Japan	274,429	373,890	415,368	420,124	406,554
Persia	243,621	381,898	474,553	587,502	937,902
Other countries[3]	12,000	12,000	12,000	12,000	12,000
Total Foreign Countries[3] ..	53,623,000	56,858,000	60,046,000	66,794,000	69,994,000
Total the World	55,175,000	58,384,000	61,720,000	66,512,000	71,745,000

Foreign Countries—	1918.	1919.	1920.	1921.
Austria	765,000	—	—	—
France[1]	6,867	49,678	58,750	54,680[5]
Germany[3] ..	87,900	36,800	34,400	37,692[4]
Hungary	—	—	—	—
Italy	4,840	5,682	6,349	5,723
Poland (Galicia) ..	—	818,300	752,729	693,547
Rumania	953,044	841,792	1,091,102	1,149,636
Russia	3,756,000	4,342,000	3,771,000	3,971,000
Egypt	277,355	220,695	145,572	179,732
Mexico	9,353,518	13,363,553	23,675,138	29,655,339
United States ..	50,846,817	54,052,430	63,275,570	67,454,710
Argentina ..	194,313	189,829	235,435	247,214[4]
Peru	329,618	343,046	367,281	480,815
Venezuela	49,895	45,175	68,421	214,640
Dutch East Indies	1,735,800	2,015,698	2,225,034	2,323,556
Formosa	1,322	1,332	1,097	1,000[2]
Japan	347,186	318,177	316,008	317,773
Persia	1,131,489	1,194,000	1,712,267	2,381,790
Other Countries[2]	12,000	16,000	12,000	21,000
Total Foreign Countries[3] ..	69,853,000	77,854,000	97,743,000	109,190,000
Total the World ..	71,689,000	79,709,000	99,656,000	111,158,000

[1] Including Alsace-Lorraine from 1919 inclusive.
[2] Estimated.
[3] Including Alsace-Lorraine up to and including 1918.
[4] Excluding small production from privately-owned wells.
[5] Excluding shale-oil.
[6] Prussia only.

A more recent estimate, prepared for the authors by Mr. George Sell, is given in Table 2.

TABLE 2.
WORLD'S PRODUCTION OF PETROLEUM.
In Imperial gallons.

Country.	1920.	1921.	1922.	1923. Estimated or based on preliminary returns.
United States	15,519,070,000	16,526,305,000	19,513,585,000	25,399,570,000
Mexico ..	6,103,089,600	6,460,129,200	6,370,000,000	5,233,544,000
Russia ..	**907,500,000**	**924,000,000**	**1,209,000,000**	1,344,000,000
Eastern Archipelago ..	585,541,500	588,464,400	585,189,000	583,000,000
Persia ..	394,703,100	505,660,500	665,081,700	846,487,700
Rumania ..	263,875,300	301,846,100	354,678,700	391,340,400
Galicia ..	196,062,200	180,694,400	182,804,200	188,831,000
Peru ..	98,582,700	**125,000,000**	**127,000,000**	128,000,000
Japan and Formosa .	93,205,000	**91,000,000**	**90,000,000**	88,000,000
Argentina ..	50,963,600	51,247,500	71,087,400	80,000,000
Venezuela ..	17,360,000	**50,000,000**	**70,000,000**	100,000,000
France ..	13,601,800	13,766,500	19,101,000	17,511,900
Germany ..	8,418,700	**9,000,000**	**11,000,000**	13,000,000
Italy ..	1,360,500	1,317,300	**1,300,000**	1,300,000
British Empire—				
India ..	293,116,800	305,683,200	298,504,100	298,000,000
Trinidad ..	72,906,000	82,395,600	85,566,300	90,000,000
Egypt ..	37,281,100	51,376,000	**45,000,000**	35,000,000
Sarawak ..	35,138,100	49,632,200	100,178,900	135,000,000
Canada ..	6,868,800	6,563,900	6,267,400	6,160,000
United Kingdom	102,100	91,400	32,800	7,500
Total ..	24,698,746,900	26,324,173,200	29,805,376,500	34,978,752,500

Figures in black are estimated.

The great bulk of the petroleum produced is refined, except in those cases where the oils are so low in grade as to yield little or no commercial products except boiler fuel. But this state of affairs is by no means likely to persist. The development of the internal-combustion engine for the use of heavy fuel on the one hand, and the ever-developing resources of the petroleum technologist on the other, will assuredly result in the working up of even the lowest valued oil into high valued products. The main refinery products are :—

PRINCIPAL REFINERY PRODUCTS FROM CRUDE PETROLEUM.

Name.	Specific gravity range.	Initial and final boiling points, ° C.	Remarks.
Naphtha / Gasoline (Benzine)	0·728 to 0·759 .. / 0·639 to 0·780 ..	95 to 150 .. / 31 to 190 ..	— / —
Kerosene	0·785 to 0·811 ..	140 to 310 ..	—
Gas-oil	0·816 to 0·855 ..	300 to 350 ..	—
Fuel-oil	0·85 to 0·96 ..	300 and upwards ..	Not more than 1% of sulphur.
Lubricating oil ..	0·882 to 0·905 ..	300 and upwards ..	Free from sulphur & asphalt.
Residual oil	9·928 to 0·96 ..	— ..	—

The lightest product, benzine or gasoline, is in greatest demand as motor fuel, and the tendency to-day is to increase this fraction by the most careful dephlegmation during distillation. Furthermore, by cracking the heavier distillates, such as gas oil and even residual fuel oils, the total yield of gasoline may be doubled from an average crude. Two refining schemes may be quoted :—

TABLE 3.

FULL REFINING SCHEME.

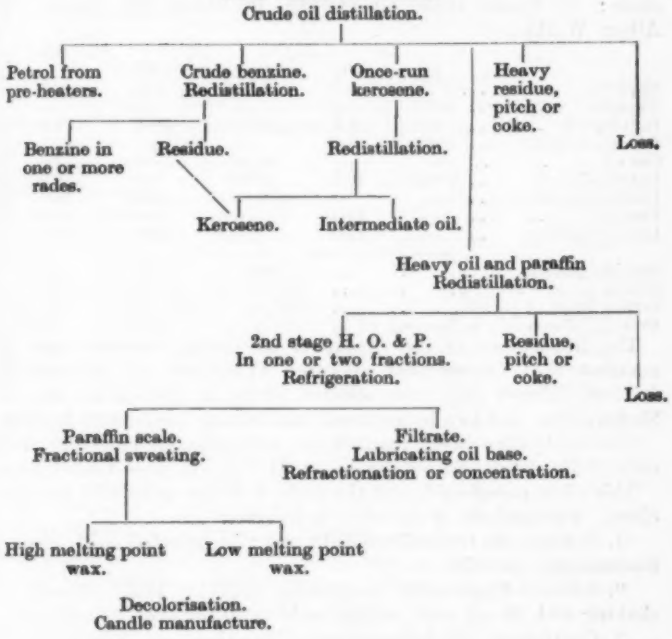
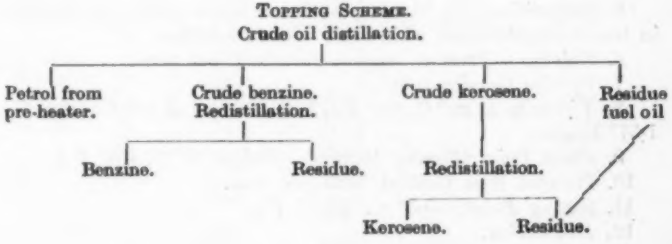


TABLE 4.

TOPPING SCHEME.



Imperial Petroleum.

Great Britain.—Seepages of petroleum have long been known in this country but are never commonly regarded as being indicative of workable amounts of mineral oil.

That these seepages are genuine petroleum is indicated in the following analysis (Journ. Inst. Petr. Techn., IV., No. 13, p. 43, 1917):—(*a*) Crude oil from Broxburn, 1866; (*b*) Oil occurring in cavities in the last mentioned sill 16 ft. below the Dunnet shale; (*c*) Crude shale oil of the Broxburn Oil Company's Albyn Works:—

	(*a*)		(*b*)		(*c*)
	s.g.	%	s.g.	%	%
Naphtha	0·700	5·0	0·740	4·5	3·5
Naphtha	0·730	5·2	—	—	—
Burning oil	0·802	34·1	0·810	36·1	32·0
Intermediate oil ..	0·840	10·5	—	—	—
Gas oil	—	—	0·840	—	4·0
Lubricating oil ..	0·865	16·7	0·865	6·6	6·0
Lubricating oil ..	—	—	0·885	19·0	18·0
Paraffin	—	12·5	—	8·8	11·0
Loss in refining ..	—	16·0	—	25·0	25·5

Specific gravity	0·830	0·866	0·868
Setting point	61° F.	65° F.	83° F.
Setting point of paraffin	103° F.	106° F.	115° F.
Bromine absorption in burning oil ..	6·5%	3%	41%

The importance of the supply of oil during the war was so manifest that Government allocated £1,000,000 for exploratory drilling. Eleven sites were selected (seven in Derbyshire, two in Staffordshire, and two in Scotland) and drilling commenced in 1918.

The Derbyshire bores reached the carboniferous limestone, but only at Hardstoft did oil appear, at 3112 ft., in more than traces.

This oil is paraffinoid, and the yield is of the order of 1 ton per diem. The analysis of the oil is as follows:—

1. *Colour.*—In transmitted light, red; in reflected light, green; fluorescence, greenish.
2. *Odour.*—Unpleasant (suggesting garlic); little altered by shaking with 10 per cent. sulphur acid or 20 per cent. caustic soda.
3. *Consistence.*—Mobility between that of kerosene and spindle oil.
4. *Water.*—Traces present.
5. *Impurities.*—(*a*) Small quantity of black solid; (*b*) chlorides in traces—opalescence with silver nitrate solution.
6. *Sulphur.*—Present, approximately 1 per cent.
7. *Specific Gravity*, 0·817.
8. *Viscosity* at 20° C. (68° F.), 2·22° Engler; at 50° C. (122° F.). 1·51° Engler.
9. *Flash Point* (Pensky Marten).—Below 20° C. (68° F.).
10. *Paraffin Wax Content*, 6·23 per cent.
11. *Setting Point*, −5·5° C. (22·1° F.).
12. *Distillation.*

True temperature. °C.	Observed temperature at 770 mm. pressure. °C.	Percentage by volume.
63	62·6	Initial boiling pt.
80	79·6	Few drops.
100	99·4	1·0
125	123·4	2·5
150	147·8	4·25
175	170·9	7·0
200	194·6	11·5
225	218·4	15·5
250	242·1	21·0
275	265·0	27·75
300	290·0	35·0
Residue = 64·0%		Loss = 1·0%

13. *Distillation.*—Charge, 2 litres, weighing 1640 gms. Commencement of distillation, temperature 18° C. in boiler, 18° C. in vapour.

Fraction No.	Fraction. Weight. gms.	Total. gms.	Total. %	Temperature, °C. Vapour.	Temperature, °C. Boiler.
1	33·27	33·27	2·03	102·0	154·0
2	32·51	65·78	4·01	130·5	174·0
3	23·85	94·63	5·77	148·0	182·0
4	35·74	130·37	7·95	168·0	192·0
5	37·54	167·91	10·2	190·5	208·0
6	37·57	205·48	12·5	200·0	216·0
7	38·09	243·57	14·9	214·0	226·0
8	38·20	281·77	17·2	224·0	235·0
9	38·75	320·52	19·5	234·0	242·0
10	38·84	359·36	21·9	244·0	251·0
11	39·60	398·96	24·3	251·0	259·0
12	39·86	438·82	26·8	258·5	268·0
13	39·64	278·46	29·2	266·0	278·0
Residue	1120·00	1598·5	97·5		
Loss	41·50	41·5	2·5		
Total	1640·0	1640·0	100·0		

Specific gravity. D.	Temp. °C.	Gms. D.	Volume. Total. c.c.s.	Volume. Total. %	Specific gravity of total.
0·665	15	50·0	50·0	2·50	0·665
0·714	15	45·5	96·5	4·78	0·689
0·728	15	39·7	135·2	6·76	0·700
0·738	15	48·4	183·6	9·18	0·710
0·750	15	50·1	233·7	11·68	0·719
0·757	15	49·6	283·3	14·16	0·725
0·763	15	29·9	333·2	16·7	0·731
0·769	15	49·7	382·9	19·1	0·736
0·774	15	50·1	433·0	21·5	0·740
0·778	15	49·9	482·9	24·1	0·744
0·783	15	50·6	533·5	26·7	0·748
0·788	15	50·6	584·1	29·2	0·751
0·792	15	50·0	634·1	31·7	0·755
0·860	15	1303·0	1937·0	96·85	
		63·0	63·0	3·15	
		2000·0	2·0000	100·00	

Analysis of Benzine Fraction (to 150° C.) from foregoing Distillation.

1. *Specific Gravity.*—0·700.

2. *Odour.*—Before treatment, very bad, unpleasant; after treatment, very good. (The treatment consisted of agitation with 2 per cent. of 98 per cent. sulphuric acid, followed by water wash, alkali wash with 20 per cent. caustic soda, and finally water wash.)

3. *Colour.*—Almost water white.

4. *Distillation.*—

Initial boiling point, 30/40° C.

60° C.	.. 2·75%	..	Final boiling point	162° C.	97·5%
75° C.	.. 12·00	..	Residue	.. ..	1·5
80° C.	.. 16·00	..	Loss	.. ..	1·0
90° C.	.. 28·00				
100° C.	.. 40·00				
125° C.	.. 78·00				
150° C.	.. 95·00				

5. *Unsaturated.*—Negligible.

6. *Aromatic Content.*—Less than 1 per cent. (A small quantity of the refined benzine was prepared. This fraction represents a very good benzine.)

Analysis of Kerosene Fraction from foregoing Distillation.

1. *Specific Gravity.*—0·769.

2. *Colour and Odour.*—After treatment (see benzine fraction) and drying the colour was almost water white and odour very good.

3. *Distillation.*—

Initial boiling point, 155/170.

	° C.			
Up to	175	..	Few drops.	
	200	..	24·0%	
	225	..	56·0	.. A small quantity of refined kerosene was prepared. This fraction represents a very good kerosene.
	250	..	85·0	
	275	..	96·0	
Final boiling pt. ..	279	..	97·5	
Residue	.. ..		1·5	
Loss	.. ..		1·0	

Analysis of Residue of foregoing Distillation.

1. *Specific Gravity.*—0·860.

2. *Viscosity.*—

Engler, at 20° C. (68° F.), 21·6°; at 50° C. (122° F.), 3·7°.
Redwood I, at 38° C. (100° F.), 160 secs.

3. *Setting Point.*—8° C. (=46·4° F.).

4. *Flash Point* (Pensky Marten).—Corrected to 760 mm. Closed=146° C. (294·8° F.); open=154° C. (309·2° F.); fire 162° C. (323·6° F.).

5. *Paraffin Wax Content* (calculated from that of total crude).—9·1 per cent.

6. *Re-distillation.*—100 c.cs. of the residue were rapidly distilled from an Engler flask.

(*a*) Fraction 1,25 c.cs, a very light oil like solar oil.

(*b*) Fraction 2,10 c.cs, a light oil not depositing any solid paraffin wax on cooling.

(*c*) Fraction 3,10 c.cs, a light oil depositing a large quantity of paraffin wax on cooling to ordinary temperature.

(*d*) Fraction 4,10 c.cs, a light oil depositing large quantities of paraffin wax at ordinary temperature. Obvious decomposition began at this point.

(*e*) Residue, a thick green viscous mass with large solid deposit at ordinary temperature.

Topping the Crude Oil to 200° C. and Examination of Residue.

Volume of tops, 13·2 per cent.; volume of residue, 86·8 per cent.

Specific Gravity.—0·835.

Cold Test.—-3° C. (26·6° F.).

Viscosity.—

Engler at 20° C. (68° F.), 4·54°; at 50° C. (122° F.), 1·63°.
Redwood II. at 0° C. will not flow.

Flash Point (Pensky Marten) corrected to 760 mm. Closed=72° C. (161·6° F.); open=80° C. (176·0° F.); fire=92° C. (197·6° F.).

Sulphur Content.—0·97 per cent. This residue in no way approximates to a lubricating oil. Apart from the high setting point, which could be lowered by separation of the paraffin wax, the figures indicate a good fuel oil.

Distillation.—Initial boiling point, 175–200° C. Up to 225° C., 4·5 per cent; 250° C., 13·5 per cent.; 275° C., 21·5 per cent; 300° C., 31·5 per cent.

Summary.

The crude is apparently a purely paraffin base. A very good benzine representing 5·77 per cent. by weight and 6·76 per cent. by volume, and a very good kerosene, representing 23·4 per cent. by weight and 24·8 per cent. by volume, can be obtained by the B.P.M. distillation. Both these fractions need but little refining.

Topping to 200° C. or superheated steam distillation yields a residue with the characteristics of a fuel oil, provided the paraffin wax is removed.

The residue, after the benzine and kerosene fractions have been removed, in the B.P.M. distillation, may contain some lubricating fractions. On direct distillation it yields some fractions which at the most can be termed very light lubricating oils. These, however, also must have the paraffin wax removed.

A large yield of apparently very pure paraffin wax can be obtained,

The D'Arcy well at Dalkeith was struck at 1810 ft., but the well only yielded slightly to bailing. The analysis is as follows :—

Sp. gr...	0·823
Setting point	66° F.
Benzine	15·13
Kerosene	19·65
Gas oil	23·36
Lubricating oil	15·00
Wax	13·36
Residuum	3·66

References to the early history of the occurrence of petroleum in Great Britain are detailed in Redwood's Treatise on Petroleum, Vol. I., p. 38, *et seq.*

Particular mention may be made of the Kelham boring, near Newark. The bore was drilled in connection with a coal survey and oil was met at 2400 ft. The oil had sp. gr. 0·914, and was reddish brown in colour and of moderate viscosity. Its flash point was 146° F. It contained no gasoline, a little kerosene, and 7—8 per cent. of wax.

Canada.

An account of earlier development of Canadian resources is given in Redwood's Treatise on Petroleum, p. 76, *et seq.*

Production of Canada.

	New Brunswick.	Ontario.	Alberta.	Total.
1913 ..	302 ..	32,281 ..	—	32,583
1916 ..	192 ..	28,111 ..	—	28,303
1919 ..	604 ..	31,401 ..	2,348	34,353
1921 ..	1,068 ..	24,695 ..	1,029	26,792

Revised Statistics on the Mineral Production of Canada, 1922. No. 14.—*Crude Petroleum.*

October 10, 1923 (Dominion Bureau of Statistics).

The Dominion Bureau of Statistics issues the following finally revised statistics on the production of crude petroleum in Canada during 1922 :—

The production of crude petroleum in Canada in 1922 amounted to 179,068 barrels, having a sales value of $520,073. Government

bounties on these sales amounted to $91,103, making the total value $611,176 to the producers. In 1921 the production was 187,541 barrels, having a total value of $641,533. The average market value per barrel in 1922 was $2·90, while in 1921 it was $2·92.

Crude Petroleum in Canada, by Fields, 1922.

Field	Quantity in barrels.	Value less Bounty. $	Bounty paid $	Total value $
New Brunswick	7,778	28,359	4,373	32,732
Ontario—				
Petrolia and Enniskillen	64,935	173,375	34,091	217,466
Oil Springs	43,214	115,380	22,687	138,067
Moore Township	7,275	19,424	3,819	23,243
Sarnia Township	3,224	8,607	1,692	10,299
Plympton Township	695	1,856	365	2,221
Bothwell	25,681	68,568	13,482	82,050
Tilbury East	127	338	67	405
West Dover	5,482	14,638	2,878	17,516
Raleigh Township	663	1,771	348	2,119
Dutton	387	1,033	203	1,236
Onondaga	489	1,307	257	1,564
Moza Township	11,959	31,932	6,279	38,211
Thamesville	383	1,024	202	1,226
Dawn Township	217	579	114	693
Total for Ontario	164,731	439,832	86,484	526,316
Alberta	6,559	51,882	246	52,128
Total for Canada	179,068	520,073	91,103	611,176

New Brunswick Oil.

	1.	2.
Sp. gr.	0·8392	0·8363
Benzine	14%	15%
Kerosene	37·6	38·0
Heavy oil and paraffin	42·4	42·0
Sulphur	0·02	0·01
Coke and loss	6·0	4·8
Wax	3·5	

Quebec.

Oil has been obtained from the Gaspe Peninsular, but so far not in commercial amounts.

	1.	2.
Sp. gr.	0·795	0·828
Benzine	22·1%	15·9%
Kerosene	34·3	41·3
Heavy oil and paraffin	42·0	0·5
Coke	0·8	1·4

Ontario is responsible for the greatest yield, the fields being at Petrolia, sp. gr. 0·886–0·870; and Oil Springs, sp. gr. 0·849–0·843. The successful drilling of a productive well in Kent. Co. to the Trenton limestone is promising.

Alberta.

Oil from Turner Valley has the following characteristics:—

Sp. gr.	0·7609
Benzine	79·3%
Kerosene	14·0
Lubricating oil	5·3
Residue and loss	1·4

The Mackenzie Oil Field of Northern Canada (T. O. Bosworth, Journ. Inst. Petr. Techn., VII., No. 28, p. 276, 1921).—The strata exposed in the Mackenzie Oil Field district include:—

Tertiary	Shales, sandstones, and lignite.
Cretaceous	Clay-shales, and sandstones.
Devonian	Limestones, shales, and sandstones.
Silurian	Limestones, etc.

It is in Devonian only that the oil and gas have been found. The Devonian strata of the Limestone Mountain district have been thrown into a series of bold asymmetrical folds, whose axes plunge up and down, steeply and frequently.

In the synclines the soft Camp Creek series and Fort Creek shales give rise to low ground. But wherever the upward pitchings of the anticlinal axes bring the arches of the Beavertail limestone up above the general level of the land, the denudation has developed out the arches as conspicuous hills.

Four main anticlines are thus revealed where the Mackenzie River crosses the folds. At this place all of them are pitching down towards the west.

The Oil.—The oil has a paraffin base and is of high quality. The seepage oil, obtained on digging in the outcrop of the Camp Creek beds, has a greenish black colour, and a strong paraffin smell. The specific gravity is 0·905. The crude oil from the well is of light colour, low specific gravity, high gasoline content, and low cold test.

An analysis made at the Alberta University is as follows:

Specific gravity		0·845 (36° Beaume).
Distillation	70°–150° C.	22·5%
	150°–300° C.	38·5%
	300°–350° C.	33·9%
	350°–375° C.	4·1%
Loss		1·0%

Thus, in commercial terms, the oil consists of:—

Gasoline	22·5%
Illuminating oil	38·5
Light lubricants	33·9
Medium lubricants	4·1

Oil from Alberta Tar Sands.—The "oil" extracted by superheated steam resembled a soft sticky pitch and contained a considerable amount of water in fine suspension.

The sulphur content was 4·5 per cent.

It contained no readily volatile components and is extremely asphaltic and excessively viscous—practically solid at ordinary temperatures. It is, consequently, useless even as a fuel oil though it would probably be quite useful as a bitumastic binder for road surfacing.

On dry distillation down to coke—an operation of considerable difficulty owing to the excessive frothing due to suspended water—there were obtained 14 per cent. of water, 60 per cent. of mobile oil (sp. gr. 0·925) and 25 per cent. of residual coke. The distillate oil so obtained would make a good fuel oil, though as the oil is highly sulphurous the corrosion of the coking stills would be heavy. No refined products (benzine, kerosene, lubricating oils or wax) are obtainable either from the original "oil" or its distillate.

THE PROSPECTIVE OILFIELDS OF WESTERN CANADA. (*Vide* E. H. Cunningham-Craig, Journ. Inst. Petr. Techn., I., No. 3, p. 127, 1915.)

The Athabaska Field.—As already mentioned, the lower strata of the formation are known in the north of Alberta as the "Tar Sands." These are oil sands of great thickness, which are well exposed on the Athabaska river from above Fort McMurray to below Fort McKay, and over thousands of square miles to east and west. The thickness exposed reaches as much as 200 ft., and seepages of heavy oil are very frequent along the river banks, while gas is in places evolved briskly from the bed of the river. The strata lie upon a very gently undulating surface of Devonian limestone. The river has cut a deep channel through an almost flat plateau, so that excellent sections can be studied, but on the plateau itself pine forest and muskeg occupy the surface so that it is only in stream sections that evidence is obtainable. The structure is almost absolutely horizontal, though some very broad and gentle undulations, and a few purely local disturbances hardly to be dignified by the name of anticlines, have been detected.

The exposure of tar sands in Athabasca is the greatest of pitch, tar and crude oil in the whole world, and greater than that of all the rest of the world put together. The contents, presuming the whole district produced the same amount as in the part examined, would amount to 200,000,000,000 tons of oil, which would be sufficient to last the world, at its present rate of consumption, for about 2000 years.

A number of wells have been drilled to test these conditions, but difficulties of transport and severe weather conditions in the winter have prevented continuous work from being carried on. Athabaska Oils, Ltd., have drilled five wells below Fort McKay, all of which have yielded oil from the tar sands, through which, however, they pass at a depth of some 200 ft. The oil is heavy

and sluggish in its flow, but gives remarkable results on distillation, sometimes containing as much as 60 per cent. of light oils.

Some wells have been drilled down into the Devonian formation for a distance of 800 or 900 ft., and have given very interesting results. Gas and light oils have been encountered in several porous bands beneath hard cappings, and salt water occurs at more than one horizon. These lighter oils, however, do not occur in any great quantity, and are obviously filtered and derived from the younger oilrocks above.

The Flathead and Pincher Creek Fields.—The next area in which the lower groups of the cretaceous formation are seen at the surface to be petroliferous is near the International Boundary. On the Flathead River in British Columbia, especially on its tributary Sage Creek, seepages of light oil are observed, and two or three shallow wells have been drilled and have encountered oil not far from the surface.

The Calgary Field.—In the autumn of 1913 the first well of the latter company (The Calgary Petroleum Products Co.), which was located near a large gas-spring, struck a remarkably light oil, in small quantity, at a depth of 1562 ft.

A specimen was analysed with the following results :—

Specific gravity	.. ..	0·729	Sp. gr.
Benzine ..	.. ..	72% ..	0·714
Kerosene	.. ..	20·2% ..	0·793
Solid paraffin ..	.. ..	2·5% ..	
Loss	.. ..	5·3%	

It seems quite evident that this oil, which is almost water-clear, is a filtered product, or is naturally distilled from some other source and condensed.

Another recent occurrence in the field is of interest. The Moose Mountain Oil Company, drilling a well which was located some twenty miles further to the north, has had a very good showing of oil at a depth of about 1600 ft. This oil occurs in the Dakota Strata; it is dark brown in colour, with a green fluorescence, and is of paraffin base and very good quality.

A sample analysed by Mr. Edward G. Voss, gives the following results :—

Sp. gr. 0·824 (40° Baumé).

° C.	%	Sp. gr.	
Distillate below 100° C. ..	7·2 ..	0·693	Light benzines, 20·6
„ 100° C.–150° C. ..	13·3 ..	0·746	
„ 150 –200 ..	8·0 ..	0·783	Illuminating oils, 34·8
„ 200 –250 ..	11·8 ..	0·811	
„ 250 –300 ..	15·0 ..	0·839	
„ 300 –350 ..	27·0 ..	0·847	Lubricating oils, 27·0
„ 350 –370 ..	10·0 ..	0·877	

Residue pitch about 5%.

Mr. G. S. Hume of the Canadian Geological Survey reports that on the east side of the Mackenzie the Norman oil area (northwest territory) is confined to the country north of Bear Rock at the mouth of the Great Bear River and south of the sharp anticlinal ridges opposite the mouth of Carajou River. On the same side of the river the area is bounded by the Norman or Discovery range of mountains on the east. On the west of the Mackenzie the northern and southern boundaries are not so sharply defined, and the area is of considerably greater extent than on the east. It is sharply defined to the west, however, by mountains of Middle Devonian and older rocks. These mountains—called the Carajou—are drained by various branches of Carajou River.

After the initial sucess of No. 1 well, on the east bank of the Mackenzie, 53 miles north of Norman, the Imperial Oil Company began three other wells. One of these, the Bluefish Creek well, is situated at the mouth of Bluefish Creek, about eight miles down the Mackenzie from Norman. Bear Island well is on an island about two miles from No. 1 well, and "C" camp well is a little farther up on the west bank. In none of these wells has any oil been obtained. Owing to drilling difficulties operations ceased for the time being. "C" camp is the deepest well—1704 ft.—but as it is down the dip of the rocks from No. 1 well, it is not certain that it has reached the horizon from which the last supply of oil was obtained in No. 1 well.

During 1921 the Mackenzie River Oil Company drilled to the depth of about 1510 ft., eight miles south of No. 1 Imperial well and on the same bank of the river. Gas was obtained in this hole No attempt was made in 1922 to complete this well.

As is generally known, the flow of oil from No. 1 well gradually decreased from a gusher of great promise until production almost ceased. This was attributed by some to failure of the oil supply, but, as a fact, the bottom of the hole, which was in a shale formation, had caved in and effectively prevented the entrance of oil in any quantity. During the summer of 1922 this hole was deepened to 951 ft. and another flow of oil of 60 to 70 barrels a day was obtained. Although such a flow is not such as to indicate that any immense wells will be "brought in," it does demonstrate that oil is present in quantity and gives hopes that many such wells may be found.

After the Imperial Oil well No. 1 had been deepened it gave a flow of 60 to 70 barrels per day. It is on the flank of the anticlinal ridge forming the Norman range. The well was originally drilled on a seepage, and at a depth of 783 ft. a gusher was "brought in." As was stated the flow of this well gradually diminished to a negligible quantity and deepening has given a new supply. The well is now capped.

The Canadian Department of Mines reports that a consideration of the oil and gas possibilities of the lower part of the Fraser River valley east and south of Vancouver constitutes one of the main features of a report on the geology of the Fraser River delta by W. A. Johnston, recently published by the Geological Survey of Canada. Over $1,000,000 has been spent in acquiring leases and in carrying on drilling operations, but no commercial production of oil or gas has resulted. Interest, however, in the possibilities continues to attract public attention.

The area is underlain by a thick series of shales and sandstones, mostly of fresh-water and subaerial deposition. The sediments are gas-bearing to some extent, but there is little or no evidence that they are oil-bearing, except possibly to some slight extent in the lower marine parts of the rock series. The fresh-water origin of most of the sediments precludes the likelihood of oil having been formed in them. The marine phases are deeply buried, and it is not clear from the results of drilling that they are oil-bearing—at least, to any great extent.

With regard to structural features, it is pointed out that the general structure is a gentle monocline. The rocks contain many porous sandstone and sand lenses which would form good reservoir rocks, and many shale beds which might form impervious covers to prevent the escape of oil or gas, but the rock exposures and the well logs show clearly that both the sandstone and the shale occur in lenses. This is exactly what is to be expected from the fact that they are mostly fresh-water in origin and mainly alluvial plain deposits. A part is apparently marine, but the marine beds are mostly shale and do not, therefore, form good reservoir rocks. The lens-like character of the fresh-water strata and the small extent of the lenses are unfavourable features. It is concluded that the prospects of obtaining commercial supplies of oil or gas in the Fraser delta are not very bright.

The Crude Oils of Burmah and Assam (*vide* W. J. Wilson Journ. Inst. Petr. Techn., X., No. 43, 1924).

The most intensively developed and productive field of Burmah so far is that of Yenangyoung, followed by Singu and Yenangyat, all in the vicinity of the Irawadi River, and 275–325 miles from Rangoon. The crude oils from these fields are closely similar in quality to each other, although the crudes from the two latter are somewhat richer in light fractions, and the corresponding distillate fractions from each are practically identical. They are characterised by their exceptionally high content of solid paraffins, which are present in such proportion as to cause the oil to set at temperatures below about 70° F. Above the setting point the oil is a mobile liquid (viscosity about 40 seconds Redwood at 90° F.). It is not a pure paraffin base petroleum, as it contains an appreciable quantity

of asphaltum. The colour of Burmah crude oil is brown by transmitted light and green by reflected light; it possesses a pleasant odour and is almost free from water. The oil contains extremely little sulphur, and that not in a deleterious form. The small oxygen content (not shown in the analysis) is accounted for mainly in the fractions of high boiling point, in compounds of resinous and asphaltic character. A very small amount—about 0·025 per cent.—of naphthenic acids occurs in the kerosene and intermediate oil fractions; the lubricating oil fraction is practically free from acidic bodies.

Analysis.—The following is the ultimate analysis of a representative sample of mixed crude oil :—

Carbon	86·45%
Hydrogen	13·25
Nitrogen	0·2
Sulphur	0·1
Oxygen	—
	100·00

The oil contains 0·0035 per cent. of ash, which consists of the following constituents, approximately in descending order of quantity :—Iron, aluminium, silicon, manganese, zinc, sulphate, phosphate, with a little calcium and magnesium, and traces of copper, cadmium, sodium and nickel.

The specific gravity of the oil averages about 0·835.

Distillation, in absence of cracking, gives :—

Gasoline (to 160° C.)	28%
Kerosene (160°–300° C.)	35
Intermediate oil	6
Paraffin, M.P. 136° F.	5
„ M.P. 125° F.	3
„ Soft (Sweats)	2
Lubricating oil base	13
Residuum	8
	100

Burmah petroleum does not readily undergo decomposition by cracking, so that with ordinary care the oil may easily be distilled down to coke without any appreciable breaking down of the heavier oils to oils of lower boiling point or to gas. It is found, however, that in the absence of cracking the character of the distillates, particularly of the lubricating oil fractions, may vary considerably, the more complex molecules being apparently liable, under certain conditions, to undergo a re-arrangement of their constitution, which renders them less stable chemically under normal conditions of their practical application.

It is well known that many crude oils which contain paraffin cannot be made to yield the latter in crystalline form, except under

conditions involving cracking, and consequent sacrifice of a part of the paraffin and of the lubricating oil, and probably also a lowering of the quality of the latter in some degree. This does not apply in the case of Burmah oils—at any rate, those from the principal fields. Even if an excessive proportion of steam is used in the distillation, with or without reduction of pressure, the paraffin distils in good crystalline form, and is easily filtered. Only if the distillation is carried beyond the usual stage, when the paraffin is probably accompanied by other solid hydrocarbons of different constitution, does its character become partially amorphous.

The gasoline distillate is of pleasant odour, is practically free from sulphur, and requires no treatment whatever. Of the kerosene, about two-thirds of the whole is readily rendered water-white by filtration through bauxite, and, indeed, a portion at least of this also is a white distillate without any treatment whatever. The remaining one-third or so as a second quality kerosene, suitable for the requirements of the poorer classes of Indian consumers, receives no treatment. Paraffin is obtained perfectly white by bauxite filtration of the sweated scale, and lubricating oils are treated by the same agent, although a certain amount of acid is employed for these oils only.

Products.

Gasoline.—The following is a typical distillation test of a gasoline cut at 160° C., representing 28 per cent. of the crude, and having a specific gravity of 0·757 :—

Initial boiling point	58° C.
Distillate below 100° C.	25½%
„ „ 125° C.	67%
„ „ 150° C.	94%
Final boiling point	161° C.

As much as 16 per cent. of a high quality aviation, end-point 130° C., can be obtained.

The content of aromatic hydrocarbons is not quite uniform, but the following analysis of the distillates may be taken as representative :—

	In distillate to 150° C.		In crude oil.	
	By weight. %	By volume. %	By weight. %	By volume. %
Benzene ..	2·9	2·5	0·64	0·60
Toluene ..	6·0	5·2	1·31	1·26
Xylene ..	6·8	6·0	1·50	1·45
	15·7	13·7	3·45	3·31

While no figure representing percentage of naphthenes is offered, it can be stated that these compounds represent a good proportion of the gasoline fraction.

The ultimate analysis of the gasoline distilling below 160° C. is :—

Carbon	.. ..	85·8%
Hydrogen	.. ..	14·2
		100·0

This represents an average composition of practically C_nH_{2n}.

The gasoline contains practically no olefines.

Kerosene.—Inasmuch as no method has yet been established for the determination of the several series of hydrocarbons having boiling points above 150° C., less is known of the composition of the kerosene fraction. Some indication of the nature of the oils which constitute Burmah kerosene is given by means of fractional solution in liquid sulphur dioxide. This solvent exerts a preferential solubility for aromatic hydrocarbons and probably others of low hydrogen content, but as far as the author is aware only partial separations have been attained by repeated fractionations made in this way. In a typical example, a kerosene of specific gravity 0·835 gave on treatment with liquid sulphur dioxide at 0° F. :—

75% of specific gravity	..	..	..	0·809%
25% " "	..	..	..	0·914

The heavy hydrocarbons which are extracted by sulphur dioxide will not burn in a lamp unless with the formation of dense smoke, but their proportion in the first quality kerosene is not such as to render the latter unsatisfactory, as it burns normally and satisfactorily in an ordinary lamp. The unrefined yellow kerosene, consisting largely of the less volatile constituents, possesses lower illuminating value and more tendency to smokiness in burning.

The ultimate analysis of the kerosene fraction is :—

Carbon		86·5%
Hydrogen		13·5
		100·0

This represents an average composition $C_nH_{1\cdot 971n}$.

Paraffin Wax.—The paraffin is usually marketed in grades having melting points from 120°/125° to 140°/145° F. By means of fractional crystallisation from solution a number of members of the paraffin series have been separated, most of which correspond with hydrocarbons from other oils which have been identified by earlier investigators.

Melting pt. of fraction. °C	Probable identity.	Melting pt. of hydrocarbons. °C	Authority for hydrocarbon.
47·8 ..	$C_{29}H_{48}$ ..	48·0 ..	Maybery, Proc. Amer. Acad., **40**, 349.
53·6 ..	$C_{30}H_{52}$ ..	53–54 ..	Maybery, Proc. Amer. Acad., **37**, 565.
57·3 ..	$C_{26}H_{54}$ ..	56·8–57 ..	Krafft, Ber., **40**, 4783.
61·5 ..	? ..	..	
64·2 ..	$C_{32}H_{66}$ ..	63·6–64·1 ..	Do.
68·8 ..	$C_{31}H_{64}$ ..	68·4 ..	Do.
71·7 ..	$C_{33}H_{68}$ or $C_{34}H_{70}$ ..	71·8 .. or 71–72 ..	Do. Maybery, Amer. Chem. J., **33**, 285.

Paraffins of higher melting-point than the above occur in bottom settlings and in sucker-rod paraffin. From the latter a fraction melting so high as 91° C. has been obtained, but up to the present the composition of such fractions has not been investigated. Such high melting-point paraffins occur chiefly in the Singu field.

Lubricating Oils.—As shown by the analysis of the crude oil, the lubricating oils constitute a somewhat small proportion of the crude. The lubricating oil can, however, be fractionated into grades suitable for all classes of lubrication. Apart from their relatively high specific gravity, these oils possess no unusual characteristics.

The presence of substances of very high specific gravity in the lubricating oils is again shown by extraction with liquid sulphur dioxide, or more conveniently in the laboratory with a solution of the latter in acetone. Two examples of such treatment of oils which were untreated distillates are shown:—

No. 1.—Spindle oil.

	Original sample.	Extracted oil.	Residual oil.
Per cent.	— ..	16·4 ..	83·6
Specific gravity at 60° F. ..	0·9135 ..	1·0075 ..	0·985
Viscosity at 70° F.	229 ..	413 ..	204
„ 140° F.	56 ..	68 ..	54

No. 2.—Motor oil.

Per cent.	— ..	11·1 ..	88·9
Specific gravity at 60° F. ..	0·946 ..	1·037 ..	0·937

Residuum.—Burmah residuum constitutes a good fuel oil, but has the disadvantage of being solid at ordinary temperatures. Consisting largely of paraffin, it cracks readily under pressure at a low cracking temperature, giving a good liquid fuel of lowsetting point and a colourless spirit which does not deposit gum on standing for about four years.

Other Burmah Crude Oils.—Two crude oils, at present produced only in relatively small quantities, are those of Yethaya and

Palanyon. These oils are of interest in that, being closely similar to each other they differ notably from the other Burmese oils. The two oils occur in close proximity. Practically free from asphaltam, they distil to a residuum of petrolatum, which, if further distilled, yields a distillate still largely amorphous. These oils contain in some cases little or no gasoline. Analysis of representative samples are as follows :—

	Palanyon. Sample 1.	Palanyon. Sample 2. (normal)	Yethaya. (normal)
Specific gravity	0·875	0·911	0·930
Water	—	0·2%	0·2%
Distillate below 150° C.	15½%	3%	nil
„ 150°–300° C.	59%	46%	32%
Intermediate and lubricating oils	20½%	—	33%
Petrolatum	nil	25%	35%

The small field of Yenanma produces oil closely resembling that of Yenangyoung.

Assam Crude Oils.—The two chief producing oilfields of Assam are those of Digboi and Badarpur. These fields are some 400 miles apart, and the oils are of totally different character.

Badarpur Crude Oil.—The Badarpur field, which was opened up by the Burmah Oil Company, is of particular interest. The field contains many water sands, and the oil has in its history probably been in constant association with water. As a sand of comparatively light oil occurs between higher and lower sands of heavy oil.

Badarpur Crude Oil.—Is characterised by the following properties :—

(1) It is a natural fuel oil, excellent as regards viscosity and other properties as it comes from the well.

(2) Exceptionally high specific gravity.

(3) In the case of the majority of wells producing from the earlier sands, absence of gasoline.

(4) Total absence of solid paraffins, and only very little asphaltum.

(5) The solid residuum from distillation is brown, resembling rosin rather than asphaltum.

(6) Poor lubricating quality of the heavier distillates, which is not corrected by chemical treatment. The later fractions from some samples are as adhesive as glue, and have a specific gravity above unity.

(7) Unusual chemical constitution of certain hydrocarbons which have been isolated.

(8) Very pleasant odour resembling somewhat that of camphor.

The ultimate analysis shows an exceptionally low percentage of hydrogen; this is consistent with the high specific gravity :—

Carbon	88·8%
Hydrogen	10·8
Sulphur	0·1
Nitrogen	0·2
Oxygen	0·1
	100·0

This represents a hydrocarbon composition of $C_n H_{1\cdot47n}$, which is entirely unlike ordinary proportions. The content of asphaltum as determined by the ordinary methods is about 0·1 per cent.

The limitations of accuracy of an ordinary analysis in which oxygen is determined by difference leave a value of almost nil for oxygen, but oxygen is probably present in the oil, though evidently not to the extent to which the gummy character of the oil would lead one expect. It would seem that the resin-like substances which represent a large proportion of the heavier fractions are unsaturated hydrocarbons of high molecular weight associated with a small proportion of oxygen compounds.

The sample here examined is typical of most of the oils from those horizons of this field which contain no gasoline. Its specific gravity at 60 F. is 0·9775. The usual range of specific gravity of the oils from different wells is from about 0·930 to 0·990, but there are a smaller number of wells producing lighter crudes containing a small proportion (up to about 12 per cent.) of gasoline. The topped oils from these crudes resemble the normal crude oils. The distilling points of a sample of the gasoline (specific gravity 0·7585 at 60° F.) are shown :—

Initial boiling point	74° C.
Distillate below 100° C.	26%
„ „ 125	83%
„ „ 150	98%

The high density is not due to predominance of aromatic hydrocarbons, as these compounds are present in relatively small proportions :—

Benzene	0·9% by volume of gasoline.
Toluene	1·4%
Xylene	2·5%
Total aromatics to 150° C., 4·8% representing about 0·5% of the crude oil.	

A fraction of suitable boiling-point range constitutes a white spirit which has the virtue of drying more rapidly than other distillates of similar boiling points.

Dr. F. B. Thole has investigated the fraction, distilling between 160° and 270° C. The fraction was refractionated twice and concentrations of distillate were observed at 170°—180°, 190°—200°

220°—230° and 250°—260°. The percentages of carbon and hydrogen and the molecular weights of these fractions were determined, from which results the composition of the fractions was deduced :—

Fraction.	Specific gravity at 60° F.	Composition.
170°–180°	0·848	$C_{12}H_{22}$
190°–200°	0·868	$C_{13}H_{24}$
220°–230°	0·888	$C_{14}H_{26}$
250°–260°	0·900	$C_{15}H_{28}$ and (loss) $C_{12}H_{28}$

The first three fractions, which had a pronounced camphoric odour, are homologues of the series C_nH_{2n-2}, also the lesser part of the last fraction, the other compound being of another type. The fourth fraction had also a different odour.

These hydrocarbons are attacked only slowly by fuming sulphuric acid.

The ash of Badarpur crude oil amounts to *nil* to 0·2 per cent. of the crude oil, and contains (in approximate order of quantity) oxides of iron, aluminium, zinc, magnesium and calcium, with small proportions of sulphate, phosphate and silicate.

The Development of the Petroleum Industry in Assam (*vide* H. S. Maclean Jack, Journ. Inst. Petr. Techn., III., No. 12, p. 263, 1917).

Of the two areas which have been actually worked by the Assam Oil Company, the southern one, known as the Makum area, is the one on the bank of the Dehing. It is the one which first caught the eye of the early explorers, as, being conveniently near the river, it was the more easily reached. It lies on a slightly elevated plateau between the northernmost of the Naga Hills and the river, the distance between the two being about three miles. The ground is on the whole level, but a good deal broken towards the hills. The actual extent of the area is four square miles, but there are indications of oil in many places outside.

The other area, which is called the Digboi field, lies about nine or ten miles to the north, where a small range of hills crosses the otherwise absolutely flat valley of the Brahmaputra. This range appears to be a continuation of a spur of the Naga Hills, which branches off in a north-easterly direction near Jaipur. At Digboi there are steep hillocks, 40 ft. to 50 ft. high, placed very close together. Digboi is at the very end of this small range. Farther to the east the hills die away and disappear altogether.

The crude petroleum in Assam is found in intermittent deposits situated in loose sands. Considerable gas pressures are present, and on first striking the oil the well usually flows with a good deal of force.

No one of the Company's wells has proved to be a really heavy producer, and, according to the theories which have been formed, the field is not likely to provide any big gushers, but we are quite willing to have this theory falsified. On the other hand, the wells are very good stayers, and remain reasonable producers for a comparatively long period. When the oil reaches the surface it brings with it a considerable proportion of sand, and one of the natural constituents of the oil is a heavy percentage of wax of a very high melting-point. As one might expect, therefore, the wax and sand combine to choke the well, and at fairly frequent intervals form a very hard plug. A special gang is kept constantly at work cleaning the wells as they choke, and keeping them generally in order.

The pure crude is 0·856 sp. gr., appears of a very dark brown, almost black colour, by reflected light, without the fluorescent greenish tint common to many American oils. By transmitted light at 84° F. the colour is warm sienna, and the oil is quite transparent and free from suspended particles of extraneous insoluble matter. If the oil is allowed to evaporate spontaneously on a microscope slide, under favourable conditions as to temperature, a half-inch objective shows no distinct crystals, but by the use of an eight-inch objective clusters of very minute lamelliform crystals, some foreign substances, and what appear to be parts of organic structures, become distinctly visible, embedded in a transparent yellow oil. The oil is perfectly fluid at 82° F., but at 81° F. crystals of paraffin begin to form and settle. These crystals are separate and defined; they do not agglomerate into a solid cake, but can be easily diffused through the oil by slight agitation. At 77° F. the oil loses fluidity and becomes semi-solid.

Digboi Crude Oil.—The petroleum of Digboi (Assam Oil Company) is very closely associated with deposits of lignite, and is singularly free from water. It is of similar nature to Burmah petroleum, containing an even large percentage of solid paraffins, but also more asphaltum than the Burmah oil. It is consequently darker in colour and of stiffer consistency at ordinary low temperatures Its distillates are similar in quantity to those of the latter, and are refined with equal facility.

The following is the ultimate analysis of the crude oil :—

Carbon	86·3%
Hydrogen	12·9
Sulphur	0·15
Nitrogen	0·2
Oxygen	0·45
	100·0

Below are the results of a laboratory analysis of a representative sample :—

Specific gravity at 60° F.	0·856
Completely fluid at 93° F.	
Viscosity at 93° F.: 42 seconds (Redwood)—	
Gasoline (to 160° C.)	16·8%
Kerosene (160–300° C.)	30·2
Intermediate oil	3·4
Lubricating oil base	10·8
Paraffin, M.P. 136° F.	7·6
Paraffin, M.P. 126° F.	3·1
Sweats, M.P. 96° F.	8·8
Residue	19·3
	100·0

Analysis of distillate below 105° C. :—

	%	Calculated to crude oil. %
Benzene	4·6 by volume	.. 0·7
Toluene	7·3 „	.. 1·1
Xylene	7·6 „	.. 1·15
	19·5	2·95

The ash of Digboi petroleum amounts to about 0·01 per cent., and consists (in approximately descending order of quantity) of oxides of iron, aluminium, magnesium, calcium, barium and sodium, with small amounts of sulphate, phosphate and silicate.

Paraffin wax is one of the most important constituents of Assam petroleum, which resembles in this respect most of the Eastern oils. It is a hard wax of very high melting-point, and the percentage in the crude is considerable. The melting-point adopted as a standard is 135° F., but during the greater part of the year the difficulty is to obtain the softer waxes to blend down to this average. A melting-point of 140° is quite normal for a run of wax; and when required for exhibition purposes, or something similar, wax of a melting-point of 145° and higher has been produced with no difficulty whatever. It is customary for the Company to market the wax in a semi-refined state—a bright lemon-yellow in colour.

Australia (*vide* E. C. Andrews, Econ. Geol., 1924, XIX., 157-168).

Gas samples from numerous prospecting bores have almost always proved dry, Roma being an exception. So far as Southern and Eastern Australia are concerned, the conditions appear to be similar to those of the Indian Peninsula. The little that is known of the great north-western area suggests conditions similar to those of the eastern fields of the U.S.A. In New South Wales, out of hundreds of bores in Mesozoic and Palæozoic rocks, the Connamble bore alone found a trace of oil. In the Tertiary of Victoria nothing has been found. Boring in Tasmania has been

fruitless, but a minute seepage has been reported associated with Tasmanite and coal in the Mersey River basin. In Queensland, the first Roma bore in 1900 encountered wet gas at 3683 ft. In 1908, another well at 3700 ft. brought in more than a million cubic feet of gas a day at 200–300 lbs. pressure. At Orallo, near Roma, Dr. Jensen considers conditions more favourable. In South Australia no results have been obtained. In the northern part of Western Australia solid bitumens have been found in association with carboniferous rocks, and Government geologists have considered the conditions sufficiently favourable to justify test wells at various points. In northern territory prospecting has been unsuccessful. The Australasian region appears to have been built outward from the Archæan nucleus of Western Australia, and consists of (*a*) south-western nucleus, (*b*) outer Archæan zone, (*c*) inland plains of Eastern Australia, (*d*) plateaus of Eastern Australia. Archæan rocks are closely folded. Much folding went on locally during the Palæozoic, since when movements have been very gentle. The Mesozoic was a time of shallow and fresh-water conditions. A marine fringe of Tertiaries occurs in the South. The Mesozoic and Cainozoic history of Australia differs widely from that of the oil-bearing zone of islands to the North. A parallel is drawn between Australia and the petroliferous Malayan arcs, and the continental regions of India and South Africa with the "Tethyan" petroliferous arc to their North, and the conclusion is drawn that, in spite of the oil indications described, there is little hope of finding petroleum in commercial quantities in Australia.

New Zealand (*vide* T. H. Easterfield and N. McClelland. J. Soc. Chem. Ind., 42, 39, 936–938).

Petroleum has been found in many localities, but that occurring at New Plymouth, within twenty miles of an extinct volcano, was the only source likely to produce commercial quantities, and that had to be stopped owing to failure of well casings. Analysis of this crude gave :—

Paraffin wax in above	12·0%
Pitch	1·5%

The oil, though liquid as it runs from the bore, sets to a semi-solid grease owing to the large content of solid paraffins, and was practically free from sulphur.

Further examination of this oil revealed some interesting features, as indicated by the high gravity of the distillates. The benzine and kerosene fractions both burned with a smoky flame, and gave a contraction of 36 and 30 per cent. respectively, on treatment with fuming sulphuric acid, olefines being practically absent.

After this treatment these fractions burned without smoking, but the gravity still remained comparatively high, indicating the presence of cycloparaffins.

Cycloparaffins.

The benzine fraction, after treatment with sulphuric acid to remove the benzenoid constituents, was repeatedly fractionated over a Dufton column, and the following hydrocarbons isolated :—

Fraction.	B.P., °C.	Sp. gr.	Cycloparaffin.
1 ..	69–74 ..	0·7494 ..	Methyl cyclopentane.
2 ..	78–83 ..	0·7790 ..	Cyclohexane.
3 ..	100–104 ..	0·7669 ..	Methyl cyclohexane.
4 ..	115–125 ..	0·7433 ..	Dimethyl cyclohexane + octane
5 ..	146–152 ..	0·7228 ..	(*n*-nonane).
6 ..	160–163 ..	0·7884 ..	*a*-Decanaphthene.
7 ..	179–182 ..	0·7987 ..	Undecanaphthene.
8 ..	196–198 ..	0·8042 ..	Dodecanaphthene.

Benzenoid Constituent.

The original benzine, without sulphuric acid treatment, was similarly fractionated and gave :—

Fraction 1.	Boiling below 90°		5·0%
„ 2.	„ between 90°–110°		30·0%
„ 3.	„ „ 100°–140°		47·4%
„ 4.	„ „ 140°–170°		17·6%

On treating fraction 2 with sulphuric acid, and removing the volatile hydrocarbons from the acid layer by evaporation, the benzenoid constituents were regenerated by hydrolysing the sulphonic acids with steam at a temperature above 160° C. These hydrocarbons were fractionated and gave :—

Benzene, B.P. 80°–81°	9%
Toluene, B.P. 111°	68%
Xylene, B.P. 120°–145°	17%

Benzene was further identified by conversion to *m*-dinitrobenzene, toluene to 2·4 dinitrotoluene, and the three xylenes by oxidation to the dicarboxylic acids, terephthalic acid, isophthalic acid and phthalic acid, respectively.

Toluene and xylene were also found in fraction 3. On similar treatment fraction 4 gave mesitylene and pseudo cumene identified by their trinitro derivatives.

Naphthalene and methy-naphthalenes were isolated from the kerosene fraction boiling between 150°–300° by means of picric acid.

Paraffin Wax.

The wax was repeatedly fractionated under a pressure of 15 mm., and after recrystallisation from alcohol melting points and boiling points showed all members of the series to be present from tetracosane to hentriacontane.

Somaliland.

Samples analysed from Daga Shabell, Somaliland, gave the following figures:—

Ultimate Analysis.

Carbon	86·8%
Hydrogen	11·85%
Sulphur	0·95%
	99·60%

Oxygen and Nitrogen by difference	0·4 %
Calorific value	19,330 B.Th.U.
Specific gravity at 60° F.	0·941
Colour	Black.
Flash point	264° F.
Nature of oil	Highly asphaltic.
Asphalt (by petroleum ether)	9·55%

Distillation.—The oil contained 0·1 per cent. of water and commenced to distil at 140° C. Sulphur was eliminated at 200° C., accompanied by hydrogen sulphite. The yield of kerosene distillate was 11·5 per cent. Specific gravity of kerosene distillate, 0·846. Volume too small for further experiment.

Gas oil 11·6–32·7 per cent. amounted to 21·1 per cent., and was taken off at a vacuum of 75 cms. and up to 300° C. Specific gravity, 0·878.

Lubricating oils were distilled at 75 cm. vacuum and up to 350° C. The yield was 23·7 of the crude. Specific gravity of lubricating oil fraction, 0·965.

Viscosity:—	96° F.	169 secs.	Redwood No. 1.	
	108° F.	121	„	„
	142° F.	51	„	„

On being plotted a curve was obtained from which were taken off:—

Viscosity at	70° F.	370 secs.
	100° F.	150 „
	140° F.	55 „

Conclusions.—The small amount of light distillate oil, the high flash point, specific gravity and asphaltic content point to an oil which has undergone considerable evaporation, unaccompanied by oxidation or sulphouration.

TRINIDAD.

Natural Asphalt.

One of the largest deposits of natural asphalt in the world is found in Trinidad, near the village of La Brea. This deposit, which covers an area of about 115 acres, is generally known as the "Asphalt Lake." It is estimated to have a depth of about 150 ft.

in the centre, where it is undoubtedly fed by gradual seepage from below, as the level of the lake has dropped only very slightly in spite of the removal of vast quantities of the asphalt.

The crude asphalt is an emulsion of bituminous matter, water and finely divided mineral matter, and is very constant in composition. There is naturally some slight change in character, as the asphalt gradually flows from the centre of the lake, where it is softest, to the edges, where it becomes harder. P. Carmody (Journ. Inst. Petr. Techn., VII., No. 28, p. 298, 1921) gives the following data :—

	Water.	Ash.	Bitumen.	Other organic matter.
Soft ..	29·04% ..	24·1% ..	45·6% ..	1·24%
Hard	21·4 to 27·4% ..	27·4 to 29·7% ..	40·2 to 42·0% ..	4·4 to 5·0%

Samples, after pulverising and drying at ordinary temperatures, show about 55 per cent. of bituminous matter soluble in carbon bisulphide, and about 35 per cent. of mineral matter, the balance being water of hydration, bituminous matter adsorbed by the clay, and thus rendered insoluble in carbon bisulphide.

From one edge of the lake there is a gradual steady movement of asphalt towards the sea. The asphalt from this flowing sheet is locally known as "land asphalt," and is not so uniform in composition and differs somewhat from the "lake asphalt." Carmody (*loc. cit.*) gives the following examples :—

	Soft lake asphalt.	Hard lake asphalt.	Land.	Asphalt from sea shore.
	%	%	%	%
Volatile matter	54·5 ..	53·3 ..	47·7 ..	33·7
Fixed carbon	9·6 ..	10·3 ..	9·8 ..	8·0
Ash	5·7 ..	5·2 ..	4·8 ..	4·2
Asphaltenes	14·7 ..	16·7 ..	10·4 ..	7·9
Total organic to 100 parts inorganic	207·6 ..	180·7 ..	170·1 ..	79·7

The crude asphalt is refined by heating to about 160° C. to remove water, mechanical impurities being at the same time skimmed off or settled out.

The refined asphalt, the so-called Trinidad *epuré*, has the following properties :—

Specific gravity at 25° C.	About 1·40
Conchoidal fracture and dull lustre.	
Penetration (Dow) at 25° C.	About 7
Ductility (Dow) at 25° C.	„ 2
Melting point (K. & S.)	„ 87° C.
Bituminous matter, soluble in carbon bisulphide ..	„ 57%
Mineral matter	„ 38%
Melting point of the pure bituminous matter, free from mineral matter	„ 55° C.
Ultimate analysis of the bituminous material ..	C. 80 to 82% H. 10 to 11% S. 6 to 8% N. about 0·8%

The bituminous matter of the "lake asphalt" is a true asphalt, as distinct from the asphaltites and pyrobitumens. The crude asphalt differs only from a residual asphalt made by the concentration of a crude oil in respect to its large content of mineral matter.

The refined asphalt is largely used for paving purposes, the 38 per cent. of very finely divided mineral matter which it contains functioning as a "filler."

Manjak.—Near San Fernando, on the west coast of the island, occur deposits of the so-called "manjak." This is found in veins, which are mined, just as is the "gilsonite" of Utah. This "manjak" is really a "grahamite," a member of the "asphaltite" group. Its properties are as follows:—

Specific gravity at 25° C.	About 1·17
Melting point (K. & S.)	175 to 225° C.
Fixed carbon	About 33%
Soluble in carbon bisulphide	92 to 96%
" " tetrachloride	About 54%
" petroleum ether 88° Be	13 to 18%

The largest vein is that worked at the Vistabella mine. The composition of the product throughout this vein is not constant; at the edge the Manjak is amorphous or coal-like in character; at the centre it is lustrous and like Gilsonite in appearance. The melting point of this latter type is lower and its solubility in petroleum ether,—viz., about 55 per cent.—is much greater. This clearly indicates the origin of the Manjak from a crude petroleum.

Crude Oils.

The crude oils of Trinidad, derived from within a comparatively small area, display much variety in type and composition. They range from those as limpid as kerosene to those almost semi-solid; from oils of a paraffin base to those of an asphaltic base, some being practically free from both asphalt and paraffin.

The following table gives some idea as to their diversity of character:—

Locality.	Type, etc.	Sp. gr., 15° C.	Distilling to 150° C.	Distilling 150 to 300° C.	Sulphur.
Guayaguayare ..	Wax base.	0·862	14%	46%	Trace.
" ..	Wax base. (semi-solid)	0·878	13	44	"
" ..		0·836	38	40	0·6
Tabaquite ..	Wax base.	0·795	35	40	0·6
Barrackpore ..	Naphthene base.	0·908	7	40	—
" ..	" "	0·886	23	37	0·03
Parrylands ..	" "	0·935	11	31	—
Los Bajos ..	" "	0·934	4	42	—
Point Fortin ..		0·930	8	37	—

Broadly speaking, the crude oils of Trinidad fall into three classes, emanating from three different horizons. The youngest geologically is that at La Brea. The Rio Blanco horizon yields an oil of lower specific gravity, and of lower sulphur content than that of La Brea. The lowest horizon, that of Galeata, yields oils of high grade, rich in volatile fractions and of light colour.

The majority of Trinidad oils are, however, of mixed base.

The naphthene base oils yield benzines or motor spirits, which for a definite boiling range have specific gravities higher then those made from paraffin base crudes—other things, *i.e.*, mean volatility, freedom from impurities, boiling point range, etc., being equal. The motor spirits from naphthene base oils are the better quality owing to the preponderance of the naphthene hydrocarbons. The motor spirits from these crudes may also contain about thirteen per cent. of aromatic hydrocarbons, which are valuable components. The features of chemical composition which go to add to the value of a motor spirit, have unfortunately the opposite value in the case of illuminating oils. The presence of a high proportion of naphthenes and particularly of aromatics, are responsible for the slight tendency to smoke, or susceptibility to draughts which most kerosenes from asphaltic base oils display, in common with those from crude oils of a similar nature, such as those of Venezuela and Mexico (heavy). The kerosenes from the paraffin or mixed base oils are of distinctly good quality. The distillates require very little chemical treatment.

The fuel oils vary naturally very much with the type of the oil from which they are derived. Generally these residual fuel oils can be worked up into flux and lubricating oils.

A typical paraffin base crude (Tabaquite) gave on analysis the following data :—

Specific gravity at 15° C.	0·797
Paraffin wax	2·5%
Sulphur	0·29%
Distillation Test, A.S.T.M.	°C.
Initial boiling point	48
10% Boiling to	107
20% „	130
30% „	152
40% „	186
50% „	223
60% „	265
70% „	302

Such an oil yields the following commercial products :—

Benzine of final boiling point, 160° C.	32·6%
Kerosene „ „ „ 270° C.	28·4%
Gas oil	16·0%
Lubricating distillate	21·8%

An average mixed base crude gave on analysis the following data :—

Sp. gr. at 15° C.	0·817
Visc.: Redwood 1 at 70° F.	33 secs.
Pour test (A.S.T.M.)	5° F.
Paraffin wax	1·5%
Sulphur	0·7%

Distillation Test.

Initial boiling point	65° C.
Boiling up to 75° C.	3%
" " 100° C.	8%
" " 125° C.	19%
" " 150° C.	30%
" " 175° C.	39%
" " 200° C.	46%
" " 225° C.	52%
" " 250° C.	55%
" " 275° C.	63%
" " 300° C.	70%

The crude would yield products as below :—

41 *per cent. Motor Spirit* (American Navy Specification).

Sp. gr.	0·748
Initial boiling point	51° C.
Boiling to 100° C.	23%
Final boiling point	230° C.

Made up of :—

Aromatics	13%
Naphthenes	47%
Paraffins	40%

15% *Kerosene*—

Sp. gr.	0·814
Boiling up to 200° C.	33%
Final boiling point	295
Contraction with sulphuric acid	26%

Or alternately :—

31% *of Motor Spirit* of Sp. gr.	0·733
Boiling up to 100° C.	40%
24% *Kerosene* of sp. gr.	0·803

The residual fuel oil had the following properties :

Sp. gr. at 15° C.	0·889
Visc.: Redwood II. at 70° F.	236 secs.
Flashpoint P.M.	125° C.
Sulphur	0·8%
Pour test, A.S.T.M.	1·5° C.
Conradson coking test	1·7%

A light naphthene base crude of sp. gr. 15° C.0.908 gave the following results :—

Distillation Test.

Initial boiling point.	Boiling up to 175° C.
Boiling up to 100° C.	" " 200° C.
" " 125° C.	" " 250° C.
" " 150° C.	" " 300° C.

Such an oil would yield the following products :—

12% *Motor Spirit* of sp. gr. 0·758.	
Initial boiling point	53° C.
Boiling up to 100° C.	26%
„ „ 150° C.	86%
Final boiling point	185° C.
14% *Kerosene* of sp. gr. at 15° C.	0·829
Flashpoint	85° F.
Initial boiling point	145° C.
Boiling up to 180° C.	70%
Final boiling point	225° C.

The difference between the products from this crude and the foregoing paraffin base crude are marked. The motor spirit is of higher specific gravity and obviously richer in aromatics and naphthenes. The kerosene with a much lower final boiling point and much greater average volatility, is also of higher specific gravity for the same reason. In consequence this latter type of kerosene is of relatively inferior quality from the illuminating point of view, if consumed in lamps of the ordinary type.

The residual oil from the latter type of crude, if worked up further would yield :—

A Gas Oil, 37 per cent. on the crude,

Sp. gr.	0·905
Flashpoint	150° F.
65% boiling to	300°

a normal Gas Oil.

The residue obtained by distilling off 36 per cent. of the crude had the properties of a good Admiralty fuel of viscosity 500 seconds. Redwood II. at 0° C.

By distilling further down to a residue of about 15 per cent. a soft asphalt would be obtained. In so doing, lubricating oil distillates would be obtained and such oils would be of higher specific gravity. For example :—

Spindle Oil.

Sp. gr. at 15° C.	0·950
Flashpoint .. .. About	300° F.
Visc.: Redwood I. at 70° F.	340 secs.
„ „ „ 140° F.	57 „

A naphthene base crude of :—

Sp. gr. at 15° C.	0·935
Boiling up to 150° C.	10%
150/200° C.	6%
200/250° C.	9½%
250/300° C.	16½%

gave the following results on large scale working :—

7·6% Benzine—	
Sp. gr. 15° C.	0·753
Initial boiling point	52° C.
30% boiling to	104° C.
50% „	118
70% „	134
90% „	158
1·8% Kerosene—	
Sp. gr. at 15° C.	0·828
Flash, A.P.	106° F.
75% boiling to	200° C.
2·9% Gas oil—	
Sp. gr. at 15° C.	0·868
Flash	150° F.
90% boiling to	280° C.
86·7% Fuel—	
Sp. gr. at 15° C.	0·968
Flash	151° F.
Visc. : Redwood I. at 100° F.	2090 secs.

A heavy naphthene crude oil gave the following results :—

Sp. gr. at 15° C.	0·948
Distillation.	
Boiling up to 150° C.	1%
From 150 to 200° C.	6·5%
„ 200 to 250° C.	9%
„ 250 to 275° C.	5%
„ 275 to 300° C.	6·5%
Flashpoint	45° C.
Sulphur	1·3%
Viscosity at 20° C. (Redwood II.)	124 secs.
„ „ 0° C. (Redwood II.)	1050 „

This oil would yield :—

About 1% of a light Motor Spirit.	
Sp. gr. at 15° C.	0·747
Boiling up to 100° C.	33%
Final boiling point	160° C.
15% *of a kerosene.*	
Sp. gr. at 15° C.	0·828
Flashpoint	85° F.
Boiling up to 150° C.	3%
„ „ 200° C.	49%
Final boiling point	295° C.

The benzine and kerosene being of similar quality to those derived from the light naphthene base oil. The higher boiling fractions had the following properties :—

17% *of Gas Oil.*	
Sp. gr. at 15° C.	0·894
Flashpoint	90° C.
7% *of Spindle Oil.*	
Sp. gr. at 15° C.	0·930
Flashpoint	147° C.
Viscosity, Engler at 20° C.	6·8

8% of Lubricating Oil.

Sp. gr. at 15° C.	0·950
Flashpoint	180° C.
Viscosity, Engler at 20° C.	36

Asphalt.

A 48 per cent. residue was an asphalt of dropping point 113° F., a 60 per cent. residue was an asphalt of 124° F. dropping point.

By merely topping off 6 per cent. of this crude oil a fuel oil of the following properties is left:—

Sp. gr. at 15° C.	0·959
Flashpoint	178° F.
Viscosity: Redwood II. at 0° C.	4000 secs.

The foregoing analyses represent three types of oil from the Trinidad fields. The oils found, however, show considerable variation in character and those from individual pays may diverge considerably from the three types above cited.

Sarawak.

The production so far has been obtained from the Miri field, which is situated about 150 miles South of Brunei Bay. The oil is found in sands of miocene age, which are folded into a well-defined anticline, complicated by minor faults and small overfolds.

The oil has so far been found at all depths down to about 2000 ft. The character of the oil is fairly uniform, but a distinct change with increase of depth is noticeable. The greater the depth the lower the specific gravity and the greater the percentage of volatile fractions. The oil is of distinctly naphthenic type, being free from wax and asphalt. The recent appearance, however, of an oil at the lowest levels containing paraffin wax lends some weight to the view that paraffin base oils may be found at lower depths, as is the case in East Borneo.

The crude oil is reddish-brown in colour, transparent in thin layers, of low viscosity and agreeable odour.

An average sample of the present production has the following properties:—

Specific gravity at 15° C.	0·902
Refractive index at 15° C.	1·5075
Asphaltenes	Absent.
Paraffin wax	Traces.
Ash	0·01%
Conradson coke value	0·64%
Flashpoint, Abel	61° F.
Viscosity: Redwood I. at 70° F.	41 secs.
Calorific value	10,760 c. per g.
Elementary analysis.	
Carbon	86·47%
Hydrogen	12·37%
Nitrogen	0·13%
Sulphur	0·35%
Oxygen[(diff.)	0·68%

Distillation in Engler Flask.

Initial boiling point	97° C.
Boiling up to 100° C.	0·5% by volume.
„ „ 125° C.	2·5% „ „
„ „ 150° C.	9·0% „ „
„ „ 175° C.	18·0% „ „
„ „ 200° C.	23·0% „ „
„ „ 250° C.	41·0% „ „
„ „ 275° C.	53·0% „ „
„ „ 300° C.	65·0% „ „

The crudes from various wells display much variation in character, although conforming to the main type.

	Sp. gr. 15° C.	Vol. % to 150° C.	Vol. % to 200° C.	Vol. % to 250° C.
Miri Field.				
400 feet	0·948	—	—	7
500 „	0·932	—	7	25
1000 „	0·857	29	42	55
1400 „	0·852	38	49	61
1900 „	0·828	30	41	53
Pujut Field.				
120 feet	0·955	—	—	1·5
380 „	0·949	—	—	7
1000 „	0·914	—	11	33
1300 „	0·910	—	7	26
1300 „	0·893	—	26	44
1400 „	0·897	—	22	43

A complete distillation test on the average crude oil gave the following figures:—

Fractions, 5% Vol.	Sp. gr. 15° C.	Refractive Index. 15° C.	% Sulphur.
1	0·775	1·434	0·026
2	0·795	1·442	0·024
3	0·804	1·447	0·003
4	0·820	1·456	0·035
5	0·836	1·467	0·035
6	0·843	1·469	0·045
7	0·866	1·481	0·055
8	0·879	1·490	0·060
9	0·890	1·497	0·065
10	0·900	1·502	0·075
11	0·907	1·508	0·085
12	0·914	1·516	0·10
13	0·922	1·521	0·11
14	0·933	1·527	0·13
15	0·947	1·534	0·15
16	0·961	1·542	0·15
17	0·975	1·549	—
18	0·994	1·561	—

The high specific gravity and refractive index of the fractions indicates the relative absence of paraffins. Little is known as yet as to the character of the hydrocarbons composing this crude. The volatile fractions have, however, been examined and found to contain up to 5 per cent. of aromatives. Paraffins are present only

in small proportions, naphthenes making up the bulk of the benzine. Unsaturated hydrocarbons are not present.

The oil yields about 12 to 14 per cent. of a benzine of final boiling point 200° C.

Specific gravity at 15° C.	0·786
Sulphur	0·028%
Copper corrosion test, A.S.T.M.	Negative
Initial boiling point	80° C.
4·5% at	100° C.
10% „	108° C.
50% „	136° C.
90% „	174° C.
Final boiling point	200° C.

The low percentage of fractions boiling below 100° C. and the high initial boiling point of this benzine are noticeable. This benzine requires no chemical treatment to make it fit for use in internal combustion engines.

The yield of kerosene depends on the type made, this in turn being dependent on market conditions.

A kerosene of the normal boiling range say 150–290 C. would have an unusually high specific gravity and owing to its chemical composition would not exhibit good burning qualities. A kerosene of lower boiling range amounting to about 8 per cent. on the crude, had the properties :—

Specific gravity at 15° C.	0·850
Sulphur	0·05%
Boiling up to 150° C.	8%
„ „ 200° C.	45%
„ „ 250° C.	75%
Final boiling point	277° C.

The fuel oil resulting after distilling off the benzine and kerosene fractions is a thin oil of low cold test.

Specific gravity at 15° C.	0·930
Flashpoint, P.M.	165° F.
Viscosity : Redwood I. at 70° F.	75 secs.
„ „ „ 100° F.	49 „
Pour test, A.S.T.M.	Below 20° C.
Sulphur	0·4%
Conradson coking test	0·7%
Asphaltenes	Traces.

This residual oil is thus not only a good furnace oil, but a good diesel oil too.

Further distillation of the crude oil yields gas oils and lubricating oils. These latter are the usual type, derived from naphthene base oils. The distillates are of good colour, display little evidence of cracking, and can be refined with great ease and little loss.

DISCUSSION.

The Chairman said the statement the authors had made that it was outside the possibility of any two people to bring together in one paper everything vitally required by the petroleum industry was perfectly correct, namely, the completest possible information regarding crude oils obtained from anywhere in the world. Such information was not only of value to technologists, but to geologists, chemists and the industry generally. Any of the gentlemen present who had special information with regard to the crude oils of the Empire would be doing good service by adding to the information already supplied in the paper.

Mr. E. M. Bailey said there was one remarkable feature connected with the natural petroleums found in the British Isles, namely, that most of them were of low specific gravity, and in most cases the wax had a low average melting point compared with that derived from petroleums from other parts of the world. The cause of that would be an interesting subject for discussion by geologists and chemists. He knew of three petroleums discovered in shale in Scotland, and the specific gravities of all of them were low. On the other hand, the Kelham petroleum had a high specific gravity, as mentioned by the authors in their paper. That was probably because it was associated with coal; whereas the natural petroleums found in Scotland had all, with one exception, been obtained from the shale areas. That exception occurred in a coal and iron stone pit in the west of Scotland, which he once had the pleasure of examining; and next to Pennsylvania petroleum and the petroleum from New Zealand, which he examined 25 years ago, there was no doubt that that was practically a perfect petroleum from a refining point of view. Hundreds of barrels were produced; the oil was refined with the greatest ease, and the products right up to the end were of remarkably fine quality. He congratulated the authors on their admirable paper, particularly from the point of view of the great amount of information it contained.

Dr. William Hope Henderson said the authors had dealt in their interesting paper with the crude oils of the British Empire, but as no doubt they were as familiar with the crude oils of the world, he would like to ask them what was the lowest gravity and the highest gravity of petroleum produced in commercial quantities. He had recently seen a record of some Casmalia oil in California, which had a gravity of 6·8° Bé (A.P.I.), and this partly confirmed what he had heard from drillers, who stated that some of the

heaviest oil in that locality was 6·5° Bé, coming to surface with a temperature of 130° F., and if cooled on an iron plate could be broken into pieces with a hammer. The other extreme was that of a well near Ventura (California), reported to have produced an oil of 64° Bé at the rate of 150 barrels a day, and this extremely light oil gradually increased in weight, falling to 61° Bé and later to about 55° Bé.

He desired to refer to another question, which was of scientific interest and had nothing to do with the subject of the paper from an economic point of view, but the authors might be able to give some information on the so-called animal life in crude petroleum. He had made several collections of the various forms of such life, and a sample of the crude oil containing a large number of such specimens, with two other samples which contained specimens preserved in 70 per cent. alcohol, had been sent to the Ireland Stanford Jr. University, while duplicate samples were given to Professor W. W. Watts of the Royal College of Science. He thought it would be interesting to hear of sources outside of California where such life was found in crude oil, and to what extent an investigation of this subject had been carried out in recent years.

Dr. F. B. Thole thought the authors were to be congratulated on having collated in such concise form the immense amount of information contained in this paper; the collection and classification of such a large quantity of scattered data must have involved much labour.

He confessed to a feeling of disappointment, no doubt shared by others, that so extensive an Empire should only possess 2 per cent. of the world's output of petroleum. This might be sheer ill-luck or it might be due to the fact that such large areas, especially in Australia and India, were practically unexplored—at any rate, as regards their possible petroleum deposits.

Further, it was necessary to bear in mind that there were other available sources of oil besides petroleum wells. The oil-shale industry at present only developed in a few localities would be a great industry in future years when the supply of ready-made oil was depleted. Coal was also a potential source of liquid hydrocarbons, though at present neither of these sources could compete economically with the oil well; Sir Robert Waley-Cohen on the previous day had, however, envisaged the possibility of fuel oil at £20 a ton.

Mr. H. G. Shatwell said, in reading through the paper, he had been struck by the preponderance of the existence of heavy asphaltic oils in the British Empire. For instance, there were very big deposits of asphaltic oils in Athabaska, and although the

Empire possessed only a very small percentage of petroleum oil from which petrol could be extracted, he thought there was a very great deal of work to be done on the conversion of heavier asphaltic oils into other products which would be very suitable to the petroleum industry. In his opinion, research regarding the utilisation of such oils should be carried on with increasing energy in this country. He had in mind especially the use of the Bergius, or some similar process of hydrogenation, which might possibly convert the asphalt into low-boiling fractions which would add very considerably to the value of the British Empire as a source of petroleum oils. He would be glad if the authors could give any information with regard to the value of the Norfolk shale-oil, and also if they could state whether the investigations which had been made with the object of the removal of sulphur from those oils had met with any success. It would also be of interest if the authors could give any information they possessed regarding Somersetshire shale-oil. He would be glad if the authors could express their opinion whether the new methods of absorptive refining would not be much more effective than sulphuric acid refining, because the latter meant that so much material was wasted. Another question he desired to ask was whether the Badarpur oils referred to were terpenic in nature, and also what was the nature of the ash which occurred in Trinidad asphalt.

Mr. A. Beeby Thompson thought that papers of the kind which had been produced by Dr. Dunstan and Mr. Kewley were exceedingly valuable to all petroleum technologists. Mr. Dewhurst's paper, presented the previous day, and the present paper should almost have been read together, because they jointly covered some of the most important branches of the technology of petroleum. One of the great values of chemical research in oil was to differentiate between indigenous and migratory oils. Petroleum technologists had begun to realise that in many fields some of the oil was undoubtedly migratory, while the other was still confined to the beds in which it was formed. In that connection he considered that the relationship of paraffin and asphaltic base oils had an important bearing on the subject. On quite a number of geological structures where deep wells had been drilled paraffin base oil had been struck beneath the typical asphaltic types. In a number of cases typical asphaltic oils were struck in upper Pliocene beds, while in the deeper Tertiary or Cretaceous beds paraffin-base oil were met with. For instance, in the Cretaceous and the Eocene beds of California paraffin-base oils were found beneath the Pliocene asphaltic-base oil-yielding sands. In Eastern Borneo rich paraffinous oils were found below the typical asphalt oils. In Sarawak the same feature had been revealed quite recently by

deeper drilling; in Galicia the deeper oils were generally of a paraffin base. The production of Burmah was mainly confined to beds of Miocene age and the oils were nearly all of the paraffin base type; but in the upper beds of the Yenangyoung field, near the Pliocene boundary, paraffin-free oils have been found and described by Pascoe. Rumania produces a typical asphaltic-base oil throughout the oilfields of the country, with the exception of those fields where oil is struck in beds of Meotic age, but in this formation the oil is invariably of a paraffinous character. The interesting question arises as to whether the Meotic beds are the source of Rumanian oil which has, in the process of migration into upper Tertiary beds, suffered changes in its character. No mention has been made in the paper of the large variety of oils in Barbados. As in Trinidad, many types of oil occur, varying from the very light paraffinous to the very heavy asphaltic types. In some cases the oils are obviously of secondary origin, but in other cases they appear to be indigenous, especially those with a paraffin base. Reference had been made in the paper to Somaliland oil. During the war he visited Somaliland on behalf of the British Government, and he thought the sample of oil from that country mentioned by Dr. Dunstan was not a fair sample from Daga Shabell. By sinking shafts to a depth of only 20 ft. a light paraffinous-base oil oozed from the face of the sand and suffered evaporation. They were not black oils, but green oils with a pleasant odour.

The Chairman, in closing the discussion, said that Mr. Bailey had stated that the oil obtained from a Scotch iron and coal mine was of very high quality. This country seemed to deal very largely with high-quality products, but it did not produce them in big enough quantities. The most encouraging feature of the paper was the statement that in Athabaska deposits existed which potentially were capable of supplying the world for hundreds of years to come. The fact that the oil was difficult to separate from the sand was a problem that had to be faced, but that had very largely been overcome by a very simple and ingenious arrangement devised by Feilman. The problem then had to be faced that the asphaltic sticky oil that came up to the surface gave products of little value. It was interesting to know that the suggestion put forward by one of the speakers had been taken into consideration, and that the sticky products from the Athabaska oils, if treated under high pressures by the Bergius process, gave products which were of the very highest value, yielding in fact a large amount of high-grade petrol consisting mainly of aromatics and naphthenes. The whole question of the utilisation of the products of the Empire depended very largely on the continued application of scientific

methods. Those who derided pure science little realised that by doing so they were crying down the source from which eventually the wealth of the Empire had to come.

Dr. A. E. Dunstan, in reply, said he would be very glad if Mr. Bailey would give details of any of the crude oils he mentioned for incorporation in the paper. Dr. Henderson had asked for particulars of crude oils possessing the highest and lowest specific gravities. He was inclined to think that Dr. Henderson had mentioned them himself.

Dr. Thole had expressed his disappointment at the Empire being so sparsely provided with mineral oil, but the further remarks that Dr. Thole and the Chairman had made with regard to the low temperature distillation of coals and the Berginisation of large quantities of shale oils made him very hopeful for the future. In answer to Mr. Shatwell he would point out that tar sands might be worked up by something in the nature of the Bergius process. He was sorry he could not give intimate details concerning the Norfolk and Somerset shale oils. With regard to absorptive methods of refining as against sulphuric acid methods, he thought Mr. Shatwell might take it that such methods were widely and successfully used. The Badarpur oils were not terpenic; they were of the nature of dicyclopentyls. He did not think any analyses of Trinidad asphalt ash were extant. It was quite possible that the sample of Somaliland oil which he analysed was old and had evaporated somewhat. He trusted that Mr. Beeby Thompson would supply further information for incorporation in the paper with regard to the oils of Barbados.

The Chairman said he was sure those present would desire to express their appreciation of the vast amount of work which the authors had carried out in compiling the paper.

The resolution of thanks was carried with acclamation.

The Refining of Oil-Shale.

By Edwin M. Bailey.

As a brief introduction to the subject of this paper, it may be stated that oil-shales consist essentially of mineral matter, most frequently of the nature of clay, containing or combined with widely varying quantities of organic matter of different kinds—bituminous, resinous, cellulosic—all or some of which, at certain temperatures and under certain conditions, undergo decomposition and distillation with the production of what is known as "crude oil." Whatever may be the precise nature of the oil-yielding material or materials (to which the names "kerogen" and "pyrobitumen" have been provisionally given), it is at least known that the crude oil consists chiefly of saturated and more or less unsaturated hydrocarbons. The relatively small proportions of nitrogen and sulphur present in the shale respectively originate objectionable malodorous bases of the pyridine and kindred types, and sulphur compounds such as thio-ethers, whose odour is also considered offensive: the oxygen of the shale contributes hydroxy-compounds such as cresols, while di-olefines and some of the highly unsaturated hydrocarbons are very undesirable constituents of crude oil. The removal, to a reasonable degree, of all these impurities, whose presence would affect the colour, smell, and other properties of the oil, from the mixture of pure hydrocarbons which constitute the ideal products, is the problem of the oil refiner.

The refining of oil-shale may be conveniently considered in two stages. The shale is first carefully distilled in retorts in the absence of air and in presence of steam, whereby certain organic constituents of the shale undergo decomposition and distillation with the production of crude oil and ammonia. The crude oil is then submitted to refining processes, as a result of which various grades of marketable oil and wax are obtained, the ammonia being separately converted into sulphate of ammonia. To secure the best economic result from different shales, the inter-relations of the cost of mining and retorting the shale, the throughput of shale, the quality of the crude oil and the extent of refining, the yield of sulphate of ammonia and market conditions must all be

considered. A shale from Esthonia, yielding 4 lbs. of sulphate of ammonia and 77 gallons of crude oil (yielding no wax on refining) per ton, demands different treatment from that required for a shale from Burmah, yielding 50 lbs. of sulphate and 44 gallons of oil (yielding 21 per cent. of wax on refining), or from that suited for a shale from Scotland yielding 40 lbs. of sulphate and 20 gallons of oil (yielding 9 per cent. of wax on refining).

As subjects for refining, there are certain broad distinctions between crude shale oils and crude petroleums. Shale oils seldom yield more than 75 per cent. of refined products, while petroleums generally yield over 90 per cent. of fully refined products, if, in the case of certain petroleums, the asphalt is included. Crude shale oils contain enormously larger proportions of unsaturated hydrocarbons and much greater quantities of nitrogenous bases of the pyridine and quinoline type than do petroleums, and this characteristic difference in composition partly explains why most petroleums are more readily and cheaply refined: where this is not so, it is because of the presence in the petroleum of asphaltic material from which shale oils are for the most part remarkably free. Probably the most characteristic difference between shale oil and petroleum is the fact that, when a corresponding series of fractions (kerosene, gas oil and lubricating oil) is examined, it is found that in the case of petroleums the proportion of unsaturated hydrocarbons, as relatively indicated by the "iodine number," in the fractions increases with the increase in specific gravity and boiling point of these fractions, while in the case of shale oils the proportion of unsaturated hydrocarbons is found to be in inverse relation to the specific gravity and boiling point. Gavin and Karrick have shown that certain shales from Utah, California and Colorado, when distilled, at rates which give the highest yield, in an experimental retort, produce crude oils which contain a greater proportion of unsaturated hydrocarbons than is found in the crude oil from Scottish shale. The removal of some of the highly unsaturated hydrocarbons by the polymerising and oxidising action of the sulphuric acid employed in the refining process, and the removal of nitrogenous bases by saturation with the acid, account for the much greater loss incurred in refining shale oil as compared with petroleum. The proportion of these constituents present depends somewhat not only on the character of the shale itself but also on the retorting conditions, and a crude oil of low specific gravity is therefore generally more valuable than one of high specific gravity, suffering diminished loss on treatment and consequently giving a larger yield of total refined products, the solid paraffin being also more crystalline in structure and being therefore more easily extracted.

TABLE A.

CRUDE OIL FROM THE SAME SCOTTISH SHALE, RETORTED UNDER DIFFERENT TEMPERATURE CONDITIONS.

	High sp. gr.	Low sp.gr.
Specific gravity of crude oil	0·880	0·8655
Setting point of crude oil	93° F.	85° F.
Nitrogenous bases removed by dilute acid	14·55%	10·35%
Total loss on treatment with dilute followed by strong acid	20·86%	14·04%
Specific gravity after acid treatment	0·849	0·846
Reduction in specific gravity	0·31	0·195
Total refined products	72·12%	77·63%
Yield of refined wax	14·60%	14·93%

From the refining standpoint it is therefore desirable, if economic considerations permit, to deal preferentially with shales which tend to produce crude oil of low specific gravity, and to submit all shales to such conditions of temperature in the retort that the crude oil produced will be of this finer quality: for Scottish shale a certain gradual increase in temperature is required, with temperature and throughput properly co-ordinated.

The crude oil is fully refined with a total consumption of chemicals amounting to about 2 per cent. of acid and 0·7 per cent. of caustic soda liquor by volume. Allowing for the acid recovered from the "acid tar" and used in the manufacture of the sulphate of ammonia, the amount of acid irrecoverably consumed in the refining of the crude oil is only 0·9 per cent. A high yield of ammonia is therefore a valuable economic asset of the shale.

While a high yield of solid paraffin, or wax, increases the value of a crude oil, the rarely-occurring crude shale oils which yield no wax whatever may on this account be more desirable subjects for refining than those from which only a small proportion of wax can be obtained, as the cost of plant for the extraction and refining of the wax is very considerable, while the running cost of the operation per unit of wax is greater than the entire cost of refining, per unit of crude oil. In other respects, moreover, economies may be effected, as the crude naphtha and burning oil only may be taken off in the first distillation and the residue run off from the still as heavy fuel or Diesel oil, much distillation plant being thereby dispensed with. Even from ordinary Scottish crude shale oil there was experimentally obtained, on the industrial scale, some ten years ago, with a view to the production of the maximum yield of fuel oil, with the preservation of the naphtha, wax, and as much of the burning oil as possible, the following alternative set of products:—

TABLE B.

PRODUCTION OF FUEL OIL FROM SHALE.

	Yield %.	Yield %.
Naphtha	9	10
Burning oil	–	16
Wax	9	9
Fuel oil	71	54
	89	89

The crude oil was distilled, light oils being first taken off, and the later small portion of the heavy distillate being run without steam, "cracking"; the heavy distillate was then cooled, and the solid paraffin (rendered crystalline by the "cracking" distillation) was extracted in filter and hydraulic presses in the usual way, the filtrate being fuel oil of good quality, having a calorific value of 18,990 B.T.U. per lb. (gross). Only the light oil and the crude solid paraffin required treatment, the consumption of acid being thus reduced to slightly under 1 per cent. on the crude oil, and 89 per cent. of total marketable products being obtained.

The influence of retorting conditions upon the yields and character of the products, and the economic effect as regards the daily production per unit of retorting plant, may perhaps be best illustrated by selected experimental results obtained in a full sized Scottish retort from the same sample of shale.

TABLE C.

INFLUENCE OF RETORTING CONDITIONS, IN THE PRODUCTION OF CRUDE OIL OF HIGH AND LOW SPECIFIC GRAVITY, RESPECTIVELY.

	High sp. gr.	Low sp. gr.
Specific gravity of crude oil	0·878	0·8635
Setting point of crude oil	83·5° F.	75° F.
Yield of crude oil, galls. per ton	12·69	12·45
Yield of S/Ammonia, lbs. per ton	46·60	47·30
Loss on first dist. and treatment	14·60%	11·57%
Yield of refined wax	9·58%	10·37%
Yield of refined products, % by volume	73·42	80·77
Yield of refined products, per ton of shale	9·32 galls.	10·06 galls
Throughout of shale, per retort, daily	4 tons	3 tons
Yield of refined products, per retort, daily	37·28 galls.	30·18 galls.
Yield of S/Ammonia, per retort, daily	186·4 lbs.	141·9 lbs.

The distribution of the cost of the refining of oil-shale in Scotland may be taken approximately as :—Mining, 54 per cent.; retorting, 25 per cent., S/ammonia manufacture, 12 per cent.; refining of

the crude oil, 9 per cent. It is therefore evident that the commercial success of the development of any shale field and of a shale oil industry will be largely dependent upon the cost at which the shale can be supplied to the retorts.

Much valuable and interesting information regarding the characteristics of North American shales has recently been made available in the published work of several able and enthusiastic investigators in the United States, but, comparatively speaking, the shale developments of the world have not yet been placed on quite a proved industrial basis, except possibly in France and Scotland, and for this reason the refining of oil-shale as carried out in the Scottish Shale Oil Industry will now be particularly described.

Production of the Crude Oil and Sulphate of Ammonia.

From the mine-head the shale is conveyed in trucks by an endless wire rope to the "breaker," where it is broken into pieces about 4-inch cube by passing between revolving heavy cast-iron rollers fitted with wedge-shaped blunt teeth made of specially tempered hard steel, and conveyed by trucks and endless chain up a sloping scaffold to the top of the bench of retorts, which may be composed of 64 single retorts, each of which is vertical in position and cylindrical in form. By means of a steel hopper on the top the shale is fed into the retort, the upper part of which is of cast iron, and is 11 ft. 3 ins. long and 2 ft. diameter at the top, tapering outwards to 2 ft. 4 ins. at the bottom. The lower part is constructed of firebrick, and is 22 ft. 8 ins. long and 2 ft. 4 ins. diameter at the top, tapering outwards to 3 ft. at the bottom. The retorts are arranged in sets of four within firebrick heating chambers in the bench. Each pair of retorts has a hopper common to both, and the whole structure of the bench is carried on brickwork piers, which enables the spent shale to be discharged into trucks which are run under the bench on rails. From the top hopper which is either charged every six hours or sufficiently large to contain enough shale to supply the retorts during twelve hours, and so to enable night-shift duty in charging to be dispensed with, the shale travels slowly down through the retort as the spent shale is discharged at the bottom by the mechanism to be described immediately. In its passage downwards the shale itself is exposed to a gradually increasing temperature, ranging from about 270° F. at the top of the cast-iron section to about 1300° F. near the bottom of the firebrick section; the temperature of the shale at the bottom of the cast-iron portion being about 480° F., and the temperature near the bottom of the firebrick portion about 1300° F.

The temperatures of the external heating chamber range from about 1000° F. near the top to about 1800° F. near the bottom of the retort. From the bottom of the firebrick portion the shale passes down through a firebrick cone into a cast-iron chamber in which is situated a circular horizontal plate or table which does

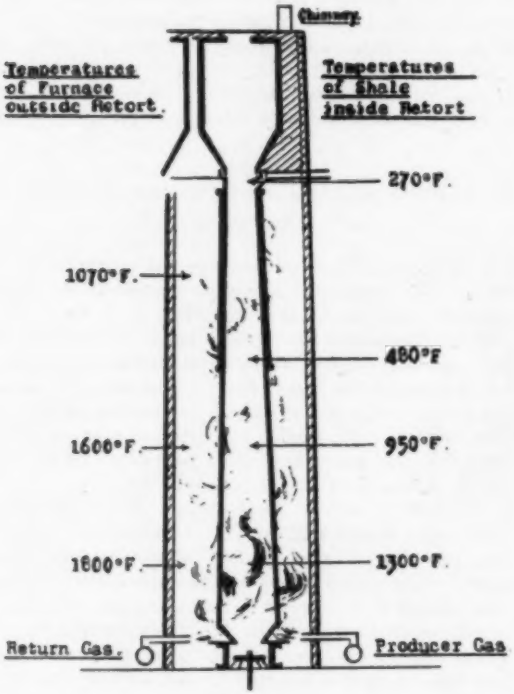


FIG. 1.
CHART OF RETORT TEMPERATURES.

not fill the chamber but which leaves an annular space. The whole column of shale in the retort is supported by the cone and by this table, and, by means of the slow circular motion of an arm attached to a spindle passing up through the centre of the plate and worked by a metal bar extending the whole length of the bench and driven by motor mechanism, is swept over the edge of the table into the annular space and so dropped into a cast-iron

discharge hopper, from which it is emptied every four hours into trucks which run beneath it and which are conveyed by an endless chain to the spent shale refuse heap or bing. A single retort of this Scottish type deals with 4 tons of Scottish shale per twenty-four hours. The retorts are heated by the incondensable gases produced from the shale itself in the retorting process, and, in the case of the poorer shales, the necessary additional gas is supplied from external coal gas producers, sometimes of the ammonia-recovery Mond or similar type. By the use of the latter, at a works dealing with 1000 tons of shale per day, the final economic outcome was equivalent to a reduction of about 5s. per ton in the price of the coal that had to be supplied for heating the retorts, when coal was costing about 10s. per ton. The incondensable gas from the shale, along with any necessary auxiliary producer gas, is led in a spiral direction round the retort externally from bottom to top in the brick chamber surrounding it, the waste gases escaping by chimneys at the top of the bench. A quantity of steam, corresponding to at least 75 gallons of water per ton of shale, and consisting of the exhaust steam from the turbines at the power plant, is introduced into each retort at the bottom hopper, forming, in contact with the carbon of the hot shale, gases of considerable heating power while also increasing the yield of ammonia and protecting both the ammonia and the oil vapours from decomposition due to excessive exposure to radiant and conducted heat from hot surfaces by diluting them and sweeping them rapidly up out of the lower highly heated zone into the outlet pipes situated just below the upper hopper and into the large gas main and thence to the atmospheric condensers. The steam, moreover, serves to cool the hot spent shale and is itself thereby further heated and, with the gases produced by its reaction with the carbon, also promotes the distillation of the shale in the upper portion of the retort and serves to equalise the temperature of the mass of shale throughout the diameter of the retort. A slight suction is maintained in the retort by means of an exhauster or fan. From the atmospheric condensers the crude oil and ammonia liquor flow through separators and thence into separate receiving vessels. The uncondensed gases are scrubbed with water to recover any ammonia present, and with oil to recover the light naphtha or crude motor spirit. For the naphtha recovery the gases are led up through a series of scrubbing towers filled with wooden checker-work, where they meet a descending spray of mineral oil (shale gas oil) which absorbs the naphtha. The oil is then led through a heater into a naphtha still, where a current of steam drives off the naphtha, both being also led through the multitubular heater and thus heating the feed of oil to the stills, after which the steam and naphtha are condensed and separated, the naphtha being collected

in a receiver as crude scrubber naphtha ready for refining. The hot oil leaving the bottom of the still free from naphtha passes through a water cooler and thence returns to the scrubbing towers, the whole system of oil being kept in constant circulation by means of pumps. In this scrubbing plant a yield of 3 gallons of naphtha per ton of shale is recovered. The ammonia scrubbers are of similar structure, water in this case being the absorbing liquid, and the resulting ammoniacal liquor is mixed with that from the retort

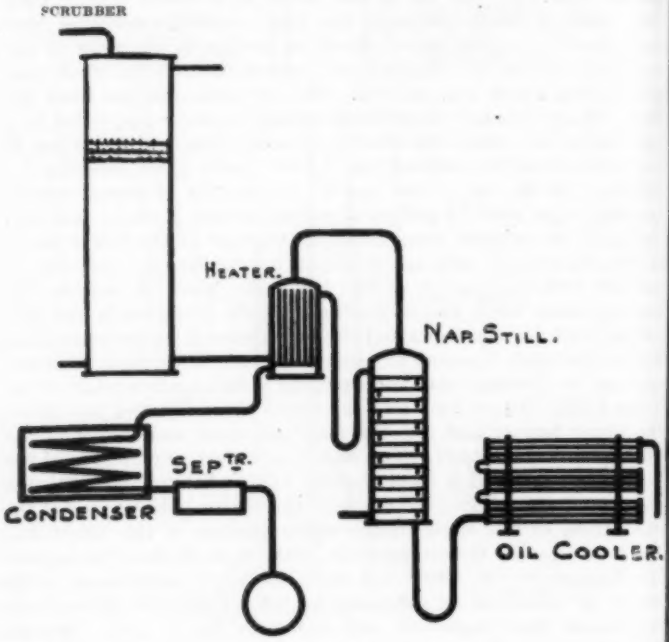


FIG. 2.
NAPHTHA PLANT.

condensers and sent to the sulphate of ammonia department for the manufacture of sulphate of ammonia.

The ammoniacal liquor is pumped into the top of an ammonia still, which is a tall, circular iron vessel containing horizontal shelves or trays over which the liquor flows, passing from tray to tray by means of short pipes, meeting a counter current of steam which is introduced at the bottom of the still, and flowing away at the bottom as waste spent liquor free of ammonia. The steam

carries off the ammonia as vapour from the top of the still into a "cracker." As non-volatile ammonia salts are present in the liquor, the requisite amount of milk of lime is pumped into the still at a point, some distance from the top, at which most of the carbonic acid which accompanies the ammonia has been evolved, thus preventing the formation of carbonate of lime, which does not liberate the ammonia from the so-called "fixed" salts so rapidly as when caustic lime is employed. The spent water can be economically maintained for long periods absolutely free from ammonia, and on leaving the bottom of the still it passes through a heat

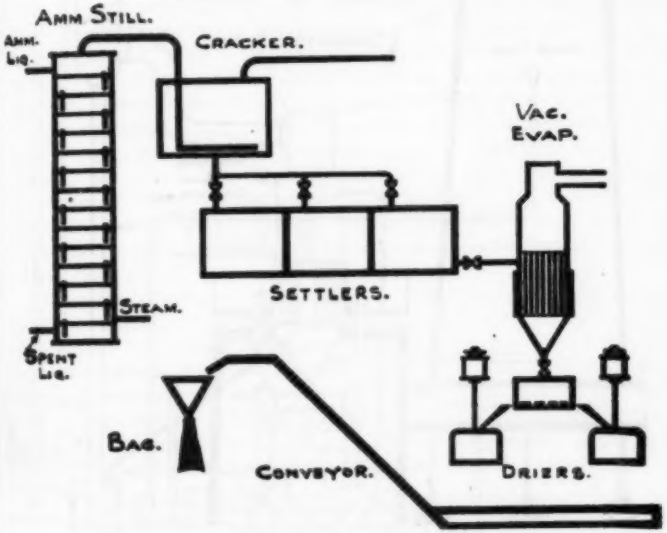


FIG. 3.

SULPHATE OF AMMONIA PLANT.

interchanger by means of which the liquor entering the still is preheated. The "cracker" is a vertical cylindrical wooden vessel, lined with lead, which is filled with the "recovered acid" obtained by washing with water the acid tar resulting from the treatment of the "crude distillate" or "green oil" in the refining process. An average "cracker" is charged with 2000 gallons of recovered acid of about 1.23 sp. gr., the strength of the acid being such as to retain in solution without crystallisation the sulphate of ammonia which will be formed by the combination of the ammonia with the acid when the ammonia and steam from the top of the still are

led into the "cracker" by means of a perforated lead pipe passing down to the bottom. When the sulphuric acid contained in the recovered acid is almost completely saturated with ammonia, the sulphate of ammonia liquor is run from the "cracker" into lead-lined wooden settling tanks, where any tar is separated, and the "cracker" is then ready for a fresh charge of recovered acid, the product of each charge being about 3¾ tons of sulphate of ammonia.

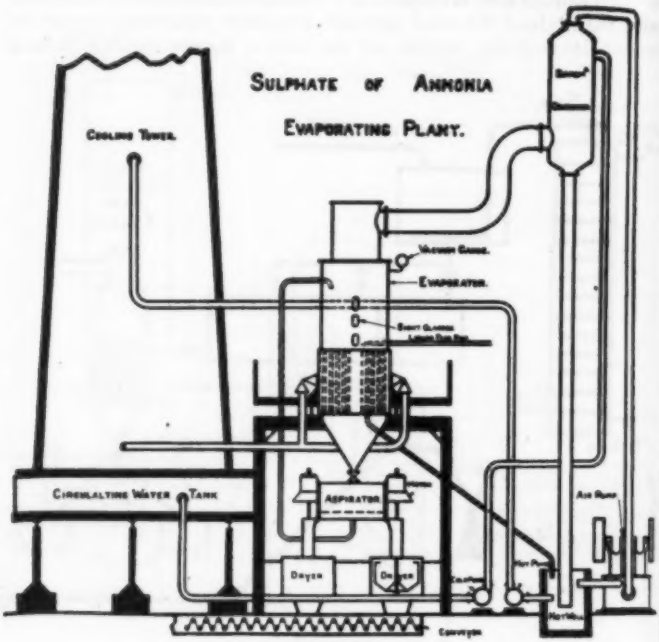


FIG. 4.

The clear, settled liquor now passes into a vacuum evaporator, where it is evaporated with exhaust steam under a partial vacuum, with the result that solid crystals of sulphate of ammonia separate out, and are dropped at intervals into a vessel below, containing a perforated false bottom, where they are drained by suction, and then emptied by means of a door into centrifugal machines, where they are dried, dropped into a trough provided with a spiral conveyor, and so carried through a final heated drying chamber into a hopper, whence the dry, neutral, granular sulphate of ammonia is delivered into bags ready for the market. The sulphate of ammonia

liquor entering the vacuum evaporator, which is made of a copper alloy, requires to be kept slightly acid in reaction to avoid active corrosion of the copper by ammonia, and in order to obtain neutral sulphate a small quantity of sulphate liquor made slightly alkaline with ammonia is poured into the centrifugal pans while in rotation, thus neutralising the excess of free acid present with the crystals, the liquor draining from the centrifugals being returned to process.

Of the sulphuric acid used in refining the crude oil, from 55 to 60 per cent. is actually recovered and used in the manufacture of the sulphate of ammonia. One ton of ordinary sulphate requires about 18·5 cwts. of acid (1·72 sp. gr.) for its manufacture. The recovered acid from the refining of the crude oil from 5 tons of average Scottish shale is sufficient for the manufacture of the sulphate of ammonia from one ton of shale. In one large Scottish refinery the recovered acid is exactly sufficient to meet all the demands for sulphate manufacture, because that refinery is supplied not only with the crude oil and ammoniacal liquor derived from the shale retorted there, but also with crude oil from other retorting works, which do not refine the oil, but which manufacture sulphate of ammonia from their ammoniacal liquor. After recovery of the acid from the acid tar by washing with water, the tar still contains about 5 per cent. of acid; it is mixed with the soda tar and the mixture burned as fuel below the stills.

The crude oil from the retorts has to be refined in order to obtain the various kinds of oil and paraffin wax in quantity and of quality as required by market conditions, the aim of the refiner being to achieve this at the lowest possible working cost and with the minimum capital expenditure on the refining plant, and to produce each type of refined product in quantity, if at all possible, proportional to its respective market value. The general principles underlying the refining operations are, very briefly, these:—

1. The separation of the various oils by distillation.
2. Their purification by means of chemical treatment.
3. The separation of the solid paraffin wax by artificial cooling and filtration, with its subsequent purification by special methods.

The application of these principles to the actual practice of the refining of crude oil in a typical Scottish refinery will now be discussed.

Distillation of the Crude Oil.

The first stage in the refining process is the distillation of the crude oil, and for the separation of the various grades of oil advantage is taken of the difference in the boiling point of these oils, the vapour of those boiling at lower temperatures mostly distilling over

first, while those of higher boiling point for the most part pass over later. As the specific gravity of a shale oil is related to its boiling point, the separation is in practice effected by condensing the oil vapours from the still and leading the condensed liquid oil into different receiving vessels, according to its specific gravity as determined on a sample taken at the outlet of the condenser coil or "worm." During the distillation steam is passed into the still, thus lowering the temperature at which the oil distils over, while at the same time preventing excessive decomposition of the oil and local overheating of any portion. In some cases a certain amount of decomposition is desirable, for reasons to be stated further on, and therefore a particular stage of a certain distillation is conducted entirely without steam. The stills are heated externally by means of a furnace underneath, except in the case of certain naphtha stills, in which only steam, with no external heating, is employed. No coal whatever is required for heating the stills, as the impurities from the oil, in the form of tar removed by the chemical treatment of the "crude distillate" or "green oil," are burned under the stills, after the recovery of the available acid from the acid tar as "recovered acid." Sufficient tar is thus obtained for all the heating furnaces required for all the distillations necessary for the complete refining of the oil, in which connection it should be remembered that, for every 100 gallons of crude oil put through the refinery, about 350 gallons of oil have to be distilled, on account of various large fractions derived from the original crude oil having to be redistilled. The total tar obtained in the chemical treatment and used as fuel at the stills amounts to about 19 per cent. of the crude oil (by volume), and of this about 28 per cent., or 5·36 gallons per 100 gallons of crude oil distilled, is used at the crude stills during the first distillation, the remaining 72 per cent. of the total tar being used at the other stills during the further stages of distillation.

While the purpose of distillation is primarily to separate the different grades of oil, a certain amount of purification is also thereby effected, especially in the first distillation, where, particularly in its later stages, heavy constituents are decomposed with the separation of carbon, or carbonaceous material, in the form of coke, which is a by-product of considerable value, the resulting distillate being of lower specific gravity and of purer quality than would otherwise be the case: the quantity of chemicals required for purification is thus somewhat reduced, and a larger yield of refined products is obtained. The yield of coke amounts to about 2·5 per cent. on the crude oil: it contains very little ash and sulphur, and is thus much superior to the gas coke obtained from coal, on which account it commands a ready market, being used in the manufacture of sodium and aluminium. The formation of coke is accompanied by the production of gases, which are

recovered, yielding naphtha and gas of high heating value, the gases which escape from the still condenser worm ends being collected into a wide pipe or main and conveyed to the retorts, where they are mixed with the retort gases leaving the condensers and scrubbed for the recovery of the naphtha they contain, the scrubbed mixture of gases being then used for heating the retorts. The total quantity of naphtha recovered from the still gases alone amounts to almost 2 gallons per 100 gallons of crude oil distilled.

The stills employed in Scottish practice are of two types, known as "boiler" and "pot" or "coking" stills, respectively. These may be used intermittently or continuously, and separately or in combination, but for the most part the distillations are carried out in the boiler type of still. These are horizontal, cylindrical, steel boilers, provided with pipes for the inlet of the oil and for the outlet of the vapour of the distillate, and with perforated steam pipes running along the bottom. These boiler stills are always used, except when the distillation is to be carried to dryness with

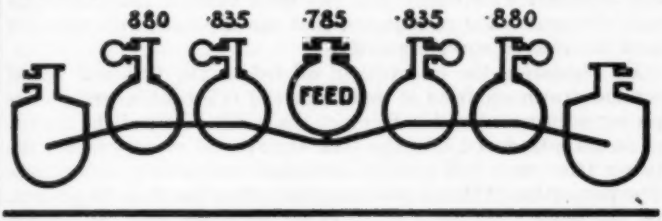


FIG. 5.

DISTILLATION PLANT FOR CRUDE OIL.

the formation of coke. In this case the "pot" still is used, which consists of a cast iron bottom with a flange, on to which is bolted a flanged, cylindrical, malleable iron top (jointed with a mixture of fireclay, brickdust, iron rust and salt), through which passes a steam pipe reaching almost to the bottom of the still, and a feed pipe for the admission of the oil. In the side of the upper portion is a door, jointed with fireclay and water, for the withdrawal of the coke, which is removed by means of pick and shovel. In the case of both boiler and pot stills, the outlet vapour pipe, in which there is a hole and metal plug to act as a safety valve, is connected with a condenser, which consists of a coil of pipe immersed in a tank through which water is circulated, the vapours in the pipe being thus condensed into liquid oil forming what is known as the "distillate," which flows from the exit end of the pipe that projects through the side of the water tank or condenser box. The distillate drops thence through a light movable metal trough contrivance into one or other of several pipes leading to receivers,

the trough being shifted from one pipe to the other as required. Alternatively, the distillate may run into a flat circular cast iron pan, divided into sections horizontally, each section leading into a separate receiver.

The first distillation of the crude oil is carried out in a combination of boiler and pot stills, a battery of which may consist of five boiler and twenty-eight pot stills. The crude oil flows from elevated storage tanks, passing first through the series of boiler stills, in each of which a portion of the oil is distilled off while the remainder passes on to the next boiler by means of a pipe connecting one end of the bottom of each boiler with its neighbours. From the bottom of the last boiler the residual oil is led into one of the pot stills for five hours, distillation taking place simultaneously, after which the feed of oil is shut off from that particular pot still and is delivered into another one in the series. The distillation in the first pot still is then continued to dryness. All the stills are heated by means of a tar spray injected and atomised with steam into the brick furnace underneath the still, the heat being so adjusted that the distillate from each still is of the desired specific gravity.

By regulating the quantity of oil fed to the first still and of residue drawn off from it and from the other stills, and by the proper adjustment of the firing of the furnace and of the amount of steam introduced into the still, the specific gravity of the distillate from each still can be controlled within very close limits. The proportion of steam used may vary from less than 10 per cent. on the lighter distillates to as much as 25 per cent. on the distillates rich in solid paraffin, the finished oils from which also require to have a high flash point. The condensed steam water is removed from the oil distillates by means of separators of simple type. The distillate from the first crude boiler still is collected separately as "crude naphtha." The last portion of the distillate from the pot stills is collected in a separate receiver and redistilled to dryness in a pot still, the distillate being run amongst the rest of the crude distillate. If this redistillation is not carried out, the crude distillate will not behave satisfactorily in the subsequent chemical treatment, as the acid tar then formed will enclose much oil, and appreciable loss of oil may result in running off the tar from the treating vessel, unless special provision is afterwards made for settling and skimming it. Towards the close of the distillation in the pot stills, the then resinous-looking distillate is run down into shallow concrete wells set on the ground below each condenser worm end, where it solidifies as a pitchy or resinous mass, which is removed to a steam jacketted vessel, melted up and settled, and run off into barrels, or into trays to form slabs. This material is commercially known as "shale resin."

Most of the distillates from the first distillation of the crude oil are mixed together, forming "crude distillate" or "green oil." The reason why they are so mixed after having been separated is that, in the subsequent treatment with acid the tar would otherwise be very thick, and the temperature of the oil would have to be so high (to maintain the oil in the liquid state, on account of the concentration of the solid paraffin in the heavier distillates) that the action of the acid would be too energetic and so result in loss of product.

Treatment or Washing of the Distillates.

The first distillation of the crude oil having been completed, the "crude naphtha" and "crude distillate" have now to be submitted to purification by chemical treatment. This operation consists in stirring the oil for a given time with sulphuric acid in definite quantity in a steel vessel called a "washer," and allowing it to settle, after which the heavy mixture of acid and impurities removed thereby, which constitutes the so-called "acid tar," is then run off. The oil is now run into another similar vessel placed beneath the first, and is stirred with a solution of caustic soda and again settled. The "soda tar" which separates out is then run off. The acid and soda tars obtained in the treatment of the various oils in the later stages of the refining process are used in the treatment of the "crude distillate" or "green oil," being supplemented by a further agitation with fresh acid and caustic soda. The stirring is accomplished by means of compressed air passing through perforated pipes at the bottom of the vessel in which the treatment is conducted, except in the case of the volatile naphtha or spirit, where stirring by mechanical means is resorted to in order to avoid loss by the carrying off of vapour by the current of air. The vessels in which the treatments are carried out are termed "washers," and these vary in capacity from about 4000 gallons to about 40,000 gallons. The type of washer used for the treatment of the "crude distillate" is a vertical cylindrical tank with a conical bottom, and is 11 ft. 6 in. high (conical part 3 ft.) and 27 ft. diameter, made of mild steel plate, and surrounded with 4½ in. brick for insulation. It can deal with 37,000 gallons of oil at one operation. There is a 6-in. inlet pipe for the oil and an 8-in. outlet pipe at the bottom, and it has also a 3-in. outlet pipe at the very bottom for drawing off the tar. A 3-in. air pipe passes from the top nearly to the bottom of the cone for stirring, and a 2-in. acid pipe passes through the side of the tank near the top and projects a little beyond the centre of the tank, to ensure the proper distribution of the acid, by means of perforations in the pipe, so that the acid is distributed over the surface of the oil and is well

mixed with the whole contents of the washer by the air passing up through the oil from the bottom of the air pipe. The bottom or "soda washer" is similar, but is only 10 ft. 3 in. in height. The loss in volume of the crude distillate incurred through the removal of impurities as tar in the washing process at this stage amounts to about 13·5 per cent. on the acid treatment and about 4 per cent. on the soda treatment.

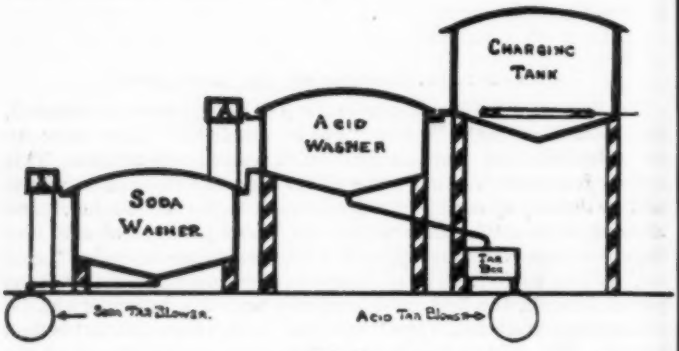


FIG. 6.

TREATING PLANT FOR DISTILLATES.

A "crude naphtha" washer may deal with about 4000 gallons per charge, and is a cast iron rectangular vessel with "dished" bottom, provided with inlet pipes for the oil and acid and outlet pipes for the treated oil and tar respectively, and with a mechanical stirrer for agitation: a similar washer is used for the caustic soda treatment, after which the treated crude naphtha is redistilled and again receives a light chemical treatment, and is finally again redistilled with steam only, and fractionated into motor spirit and various grades of naphtha, the bulk of the spirit, however, being derived from the naphtha obtained by scrubbing the uncondensed gases from the retorts. The acid used in refining is commercial sulphuric acid obtained from pyrites, having a specific gravity of 1·84. and the caustic soda is used in the form of a solution of commercial caustic soda of 1·35 specific gravity. In some refineries, both the acid and the soda required are manufactured on the spot.

The treated crude distillate is redistilled in a battery of boiler and pot stills similar to that employed for the first distillation, but sometimes only boiler stills are used at this second stage, the residue from the last boiler being drawn off without distillation and returned to the crude oil, the necessity for pot stills being thus avoided. In the former case the last portion of the distillate from the pot stills

is distilled without steam as this renders the solid paraffin which it contains more crystalline in structure and, therefore, more easily separated in the filtration process. The fractions obtained at this second distillation are :—

1. Crude Burning Oil, which on treatment and redistillation finally yields lamp oil, power oil for oil engines, signal oil for railway lamps, and lighthouse oil ;
2. Heavy Oil and Paraffin, which finally yields paraffin wax, heavy burning oil, gas oil, cleaning oil and lubricating oil ;
3. Heavy Residuum, which is returned to the crude oil, or to the "green oil."

The crude burning oil is now treated with acid and caustic soda solution, and is then redistilled in a series of boiler stills termed "Fine Oil Boilers," the residue from the last still being run off continuously through a cooler into a receiver. The fractions obtained here are :—

1. Lamp Oil or Power Oil ;
2. Lighthouse Oil ;
3. Residuum.

The Residuum is blown into a single boiler still and redistilled, giving heavy burning oil, light gas oil, and heavy gas oil. The Lamp Oil or Power Oil and the Lighthouse Oil are blown to storage tanks ready for the market.

The Heavy Oil and Paraffin is more or less solid at ordinary temperatures, owing to the presence of a high percentage of solid paraffin, and the next stage in the manufacturing process is the separation of this solid paraffin.

Extraction of the Solid Paraffin.

The extraction of the solid paraffin is accomplished by a process of artificial cooling in order to cause the formation of well-formed crystals, and the subsequent filtration of the mixture to separate the crystals of solid paraffin from the liquid oil. The oil is first cooled in open pans, or by passage down a tower through which a current of air created by a fan is passing upwards, or by passing through a water-cooled cooler, or by a combination of these methods. After being thus cooled to atmospheric temperature, the oil is pumped through a series of "Coolers," which are the refrigerating vessels for the cooling of the oil to very low temperatures by artificial means : they consist of horizontal or vertical cast iron tubes about 20 ft. long and 20 in. in diameter, containing within them steel tubes about 15 in. in diameter, the space between the tubes thus forming a chamber for the circulation of liquid ammonia,

which is pumped in by means of a compression engine. A steel shaft with scrapers serves to keep the cooled paraffin from setting too hard on the cold surface and so preventing the whole mass of oil from being sufficiently and equally cooled. By the expansion of the liquid ammonia in the jacket of the cooler owing to the diminution of pressure, with the consequent absorption of heat, the oil in the inner tube is cooled to as low a temperature as may be desired, the temperature being regulated by the amount of oil pumped through the cooler. The ammonia vapour leaving the jacket of the cooler is again liquefied in the compression engine, and, after being cooled by passing through water-cooled pipes to absorb the heat evolved on the compression of the ammonia in its passage from the gaseous to the liquid state, the cooled liquefied ammonia again passes into the cooler jacket, and the whole cycle of processes thus goes on continuously. There is a certain unavoidable loss of ammonia due to leakage, but this need not exceed 36 pounds of ammonia per million gallons of crude oil. Four of these cooling tubes are capable of cooling 11,000 gallons of heavy oil and paraffin from 70° F. to 30° F. in 24 hours. The cooled oil leaving the cooler is now pumped through a pipe into a series of filter presses. A single filter press may contain as many as 180 plates. These are set vertically in a cast iron frame work erected sufficiently above ground level to allow room for a shallow metal trough fitted with a spiral conveyor running along beneath the filter plates, so that when the filters are emptied the cakes of solid paraffin will fall into the trough and be conveyed by the action of the spiral conveyor to the floor of the hydraulic press department. The plates are hung by snugs on each upper side to the upper sides of the framework, which is somewhat longer than the combined length of all the plates, so that, for purposes of emptying, each plate can be moved along the framework sufficiently apart from its neighbours to allow the cake of solid paraffin to drop or to be scraped off into the trough beneath. The plates are corrugated, with a spout or outlet at one of the lower corners for the outflow of the filtered oil into another narrow trough, which runs along the length of the filter press just below these spouts. Each plate has a circular hole through its centre, by means of which, when the plates are screwed close together, the oil from the cooler can pass from one to the other, filling up the spaces left between the concave or hollowed outer sides of each plate. Over the top of each plate there is folded a sheet of strong filter cloth, and the plates are screwed up close together by a powerful hand-screw, or by hydraulic pressure applied at one end of the filter press. Under the pressure of the pump, the oil is forced through the filter cloth and passes out through the hole at the bottom corner of the plates into the spouts, whence it flows into the trough and is led

away into a receiver. The mass of crystals forming the solid paraffin, on the other hand, is retained between the surfaces of the cloth covering the adjoining plates, and after six hours, when the filter presses are ready, the feed of oil from the cooler is shut off and diverted into another filter press, and the plates are slid along in rotation by the men, who loosen the cakes of paraffin from the cloth with blunt knives, thus dropping them into the trough below, whence the conveyor delivers it out in heaps on the floor of the hydraulic press room, where it is packed in strong twilled hempen or cotton cloth and submitted to a much higher pressure in hydraulic presses. After six hours the cakes of crude solid paraffin are removed by the men. This crude solid paraffin is technically known as "scale," from its crystalline, flaky appearance. It has a melting point of about 115°F., and contains from 5 to 10 per

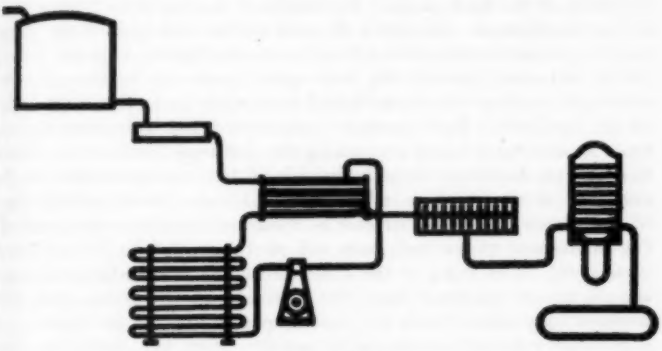


FIG. 7.

PARAFFIN EXTRACTION PLANT.

cent. of oil. It is melted with open steam in a melter along with the solid paraffin obtained by cooling and pressing the gas oil and lubricating oil from later stages, and pumped to storage tanks at the wax refinery for purification. The oil which drains away from the filter presses and hydraulic presses is ultimately treated with acid and soda, and is then distilled in what are termed "blue oil stills" of the boiler type, sometimes fitted with atmospheric fractionating condensers: the oil at this stage, before treatment and distillation in the blue oil stills, is known as "blue oil" on account of its colour. From the blue oil stills heavy burning oil, gas oil, cleaning and lubricating oil distillates, and residuum oil are obtained. These are cooled, filtered, and hydraulic-pressed, the solid paraffin being mixed with that previously obtained, while the filtered oils

are dealt with for the production of finished products. The gas oil receives no further treatment, but the cleaning and lubricating oils are finally treated with acid and carbonate of soda (or "soda ash," as the commercial article is termed). The successful treatment of the lubricating oil from shale is much more difficult than the treatment of similar petroleum oils.

During the distillation of the blue oil particularly, great attention must be paid to the regular firing of the stills and to the proportion of steam employed, in order to secure distillates of the required flash point, viscosity and colour. To obtain the high flash point (over 360°F.) for a heavy lubricating oil it is imperative that the distillation should proceed regularly throughout, as the production of even traces of light vapour through partial decomposition due to overheating is sufficient appreciably to lower the flash point of the distillate, and want of attention to this point leads to disastrous lowering of the flash point. By means of a system of "pockets" in the condensers, distillates of good colour and high flash point can be obtained with less difficulty, as the lighter vapours which would otherwise lower the flash point pass on further in the condenser, and so can be collected separately from the main body of the distillate. The "pocket" system consists in leading a pipe, from a point about half-way along the condenser line, which leads the heavier distillate through the side of the condenser tank to be collected in the receiver, while the lighter and more volatile distillate passes on as vapour and is condensed in the second half of the condenser worm and runs out at the outlet to be collected separately. The firing of the stills during the lubricating oil stage should be so regulated that the distillate at the worm end will increase only about three degrees in specific gravity per hour.

By the removal of the solid paraffin from the distillates the specific gravity of the oil is raised, as the former has a lower specific gravity than the oil which accompanies it in the distillate: gas oil rises about 10 degrees and lubricating oil about 5 degrees in specific gravity. The chemical treatment lowers the specific gravity, as the tarry impurities have a higher gravity than the purified oil. The flash point may be slightly lowered by removal of solid paraffin, and slightly raised by treatment, while the viscosity is somewhat increased by extraction of the solid paraffin, and somewhat lowered by the chemical treatment. For all these reasons it will be apparent that in the cutting out or separation of the different distillates at the blue oil distillation, in which these are separated according to the specific gravity of the distillate as it runs from the worm end of the condenser, this increase and decrease in specific gravity (and to a lesser degree in flash point and viscosity) must be allowed for, in order to insure that the finished product will be up to standard quality in these respects.

Refining of the Crude Solid Paraffin.

The first stage in the purification of the crude solid paraffin is the process called "sweating," which is carried out in so-called "sweating-houses." These are built of brick and may measure 52 ft. by 16 ft. by 12 ft. in height, and may consist of two storeys. The house is provided with close-fitting iron doors at each end, and along each side of the house, lengthwise, there run a series of steam pipes, by means of which the temperature of the inside of the house can be regulated. Supported by racks made of iron piping, there are erected in the house a number of large shallow iron trays or pans, about 21 ft. by 6 ft. 6 ins. area and 6 ins. deep, placed horizontally one above the other, and resting on transverse steam heating pipes fitted in vertical standards. By means of an ingenious arrangement of lever and eccentric, the pans are so balanced that they can be slightly lowered at one end or raised again to the horizontal position as required. In each pan, two inches from the bottom, rests a false bottom consisting of lattice-work made of thin strips of metal plaited together. With the trays in a horizontal position, and by means of the short branches of a vertical pipe fitted with stop-cocks running up one end of the trays in a central position, water from a pond is admitted so as just to reach the level of the false bottoms of the trays, and the melted crude solid paraffin, mixed with sufficient sweatings from previous operations to reduce the melting point of the mixture to about 107°F., is run in from the charging tanks, situated above the sweating houses, by means of another pipe on to the top of the water until the pans are full. The doors of the house are left open until the melted material has cooled and become solidified, after which the trays are inclined by means of the lever and the water is run off by the outlet pipe placed at one end of the trays into iron cups communicating with a vertical pipe connected with a horizontal pipe which runs off to the pond or to receiving vessels as required. The water having been run off to be used again, the cakes of crude paraffin are thus left resting on the false bottoms of the trays. The doors of the sweating-house are then closed, and the temperature is gradually raised by means of the closed steam coils. As the paraffin is heated it expands and becomes porous, and the yellow oil which it still contains, along with the portions of paraffin of lower melting point, gradually oozes out, finds its way into the space below the false bottoms of the pans, and runs away by the short off-take pipes into a receiving vessel. The solid paraffin, through the removal of the oil and some of the paraffin of lower melting point dissolved by it, thus becomes whiter in colour and of higher melting point. The oil which first leaves the sweating pans is collected in the receiver (up to 90°F.

setting point) and re-sweated by itself, yielding "residue oil," which is returned to the oil refinery, and soft wax of very low melting point. The next fraction oozing from the pans is called "strainings" or "sweatings," and is partly returned to the crude paraffin to reduce its melting point, and partly re-sweated yielding more sweatings, and soft wax (melting point 110/115°F.). When these have been collected, and when the colour and melting point of the sweated paraffin left in the trays are as desired, the melting point being about 117°F., the temperature of the house is quickly raised and open steam is admitted by the branches of the steam pipe (which is used in common for supplying steam and water to the pans) until the whole of the wax is melted and run off by the pipe into a separate receiver. This is known as "once-sweated wax." The reason for reducing the melting point of the crude paraffin by admixture with sweatings to 107°F. is to leave a sufficient range of melting point between the material as charged into the sweating-house and the once-sweated wax to allow as much as possible of the colouring matter and oil to be removed without undue loss in yield of sweated wax through the removal of too much solid paraffin with an accompanying too great rise in its melting point. For the same reason, the sweating process must not be rushed too rapidly, but time ought to be given to allow for the gradual elimination of the yellow oil so as to get the maximum yield of wax of the best possible colour left in the trays.

The once-sweated wax, after separation from the water in the receiver, is pumped up into the trays of another sweating-house, to be again cooled and re-sweated, yielding strainings of soft wax and leaving in the trays hard wax of good colour and of melting point either 119° or 122°F. (two common marketable grades) or indeed any special melting point required up to 140°F., though in this case the yield of finished wax is very small. The hard wax is melted up and run out and collected in another receiver. On account of the long time required (especially in warm weather) for the cooling of the crude paraffin in the trays, a large number of such sweating-houses are required in proportion to their output of wax.

Each grade of wax as it leaves the sweating-houses is steamed with open steam in the receivers and thoroughly settled, after which it has to be further refined by filtration through some decolorising material, in order to improve the colour and smell of the wax.

Such decolorisers as "Prussiate Char" (a by-product from the manufacture of yellow prussiate or ferro-cyanide of potash); "Eponite," made from a mixture of fullers' earth and a highly active wood charcoal; "Norite" and "Purit," much used in sugar refining, have all been employed in the past, though it may

be remarked that a material which may be excellent as a decoloriser for other substances may be very inefficient as a decolorising agent for wax. Such materials as these, thoroughly dried and in a fine state of division, were stirred with the wax by mechanical means, but the best of them failed to give a pure white wax in practice, whatever the proportion used, a greenish tint being always observable when the large cakes of wax were piled up in bulk.

Great success, however, has for over ten years attended the use of a material called "Floridin." This is a particular form of fuller's earth found in Florida, U.S.A. It has the remarkable property of adsorbing and thus removing the colouring matter from oils and wax which are filtered through it. It is used in a granulated form (16 to 30 mesh per inch) and is previously ignited to a temperature of about 900°F., it being most important that all moisture, free or combined, should be driven off before use. While, when finely powdered, floridin removes much of the colouring matter of the wax when stirred with it, by far the best results are obtained by filtration through a long column of the material, and this is the method always employed. The filter consists of an upright cylinder, made of mild steel plate, 14 ft. 3 ins. high and 2 ft. 6 ins. in diameter, the lower half being jacketted and having half-inch steam inlet and outlet pipes to keep the wax in a melted condition and at a comparatively high temperature during the process of filtration. There is a 2-inch inlet pipe for the wax at the top and a similar outlet pipe for the filtered wax at the bottom. On the bottom of the cylinder there is a sloped casting with a vertical door 2 ft. 5 ins. long and 9 ins. high.

Level with the bottom of the door there is a perforated mild steel plate on which a cloth is laid to enable the filtered wax to run through while retaining the particles of floridin. The previously ignited floridin is run from a hopper into the filters, each of which holds about a ton. The sweated wax is then run in from a storage vessel placed above the filter, and allowed to percolate slowly down through the mass of floridin. The rate of flow must be adjusted so as not to be too rapid, as time must be allowed for the decolorising effect to be obtained, and the presence of moisture in the melted wax and in the floridin must be rigidly guarded against. The upper surface of the floridin in the filter must also always be kept covered with the entering wax during the process of filtration, in order to exclude the presence of moist air. Samples are taken from the wax outlet pipe as it delivers through a cloth filter screen into a receiving vessel, and when the colour begins to show a yellowish tint, or when the bulk of the filtered wax is of the correct standard colour, the flow of wax entering the filter is cut off. The white filtered wax is then pumped to a storage tank and run into trays

arranged in racks, from which the cakes of finished wax are turned out next morning and packed in bags or wooden cases ready for the market. It is found best first to run the hard wax through the filter, and then to run the soft wax through, as the floridin, after its decolorising power for securing the standard colour of the hard wax has been exhausted, is capable of decolorising the soft wax up to the lower colour-standard required for the latter.

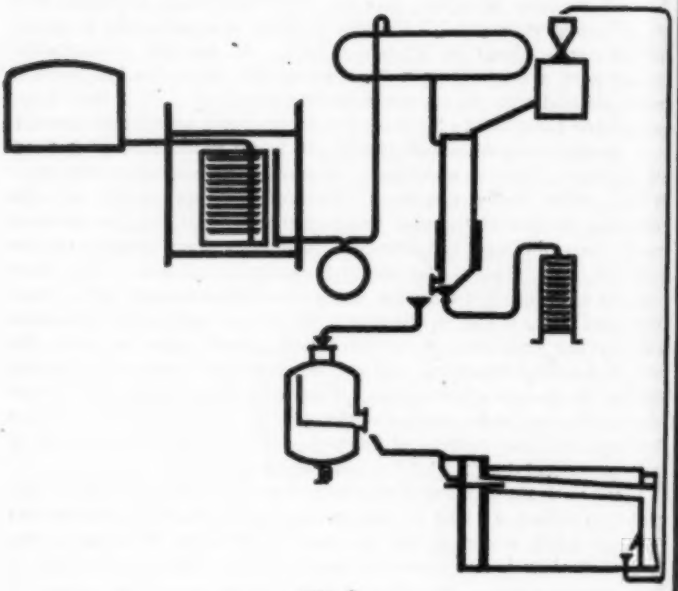


FIG. 8.

WAX REFINERY PLANT.

When the filtration of the wax has been completed up to standard colour, the filter is allowed to drain into a separate receiver, the process being accelerated by air pressure applied to the top of the filter (which is supplied with a top cover for this purpose), after which the bottom door is opened and the spent floridin allowed to run out. It consists of about 70 per cent. of floridin and about 30 per cent. of wax and colouring matter. It is removed in barrows or by a conveyor to the extractor, where the adhering wax is recovered by extraction with hot naphtha. The extractor itself is a vertical cylindrical steam-jacketted vessel divided horizontally into two divisions by a steel plate, these divisions being connected

by a syphon pipe. The upper portion is charged with about 2½ tons of the exhausted floridin from the filters (of which there is a series) through a manhole door on the top, and the door is then closed down. A sufficient quantity of naphtha is then run into the extractor from a naphtha charger situated above, by means of a pipe. Through the agency of a closed steam coil in the lower division the naphtha is vaporised and the vapours pass up by a passage at the back of the extractor, and are there condensed at the top of the upper portion by a pipe through which cold water is kept circulating. The hot condensed naphtha drops down and percolates through the mass of floridin, flowing off by means of the syphon pipe into the bottom division where the naphtha is again vaporised and again passes up as vapour to the top of the extractor, where it is again condensed and percolates down through the floridin to be again syphoned off, and this circulation goes on repeatedly and automatically until a test of the naphtha from the syphon proves that no more wax is being dissolved, and that the floridin has therefore been thoroughly extracted. Open steam is then admitted to the bottom division and to the upper division until all the naphtha has been vaporised and driven off both from the wax and from the floridin; in this case the naphtha vapours being swept right out of the extractor are condensed in an external condenser, collected in naphtha storage vessel, and are ready for use for a fresh charge of floridin. The extracted wax and colouring matter, dissolved by the hot naphtha, and being much less volatile than the latter, are left behind in the bottom division of the extractor, whence they are run off into a receiving vessel, from which they are pumped back to the sweating houses to be re-sweated. While the naphtha is an excellent solvent for the wax when hot, and while it also removes a considerable proportion of the colouring matter, some of the latter always remains, and to remove this effectively in order to restore the floridin, as finally recovered, to its original effectiveness, various other organic solvents have been experimentally tried during the last ten years. Among these may be mentioned carbon tetrachloride, alcohol, and caustic soda solution. All of these have been found to dissolve more or less of the colouring matter which is insoluble in hot naphtha, but only the use of alcohol in some form has been found to restore the original efficiency of the floridin, though its application has not yet been adopted on the manufacturing scale.

The extracted floridin from the upper division of the extractor, containing not more than 0·3 per cent. of wax and colouring matter, is removed by a man-hole door in the side of the extractor on to the floor, whence it is conveyed in barrows, or by an elevator, to the rotary furnace. This is an inclined horizontal cylindrical steel tube, lined with firebrick, 25 ft. long and 2 ft 6 ins. in

diameter, which is made to revolve by a motor-driven mechanism at a speed of eight revolutions per minute. The floridin from the extractor is introduced into the upper end of the furnace by a hopper and travels down to the lower end, whence it is discharged by means of an opening into an inclined trough from which it delivers into a pipe, through which, by the suction of a sirocco fan, it is drawn up into the charging hoppers above the filters ready for charging these again. The heating of the furnace is attained by means of a brick oven or producer in which a mixture of still coke and smithy coke is burned, the hot gases therefrom passing through the rotary furnace and thus supplying sufficient heat for the ignition of the extracted floridin, so that any traces of naphtha, wax and colouring matter, as well as all moisture, are driven off or decomposed, being ignited at a temperature of about 900°F. The recovered floridin from the furnace has somewhat less than half its original decolorising power, but can be used continuously without further deterioration, except through slight mechanical loss and production of dust which has to be periodically rejected.

Experience of the use of floridin, extending over ten years, proves that it can be repeatedly recovered and used throughout very long periods, for during an entire year only recovered floridin (except what was required to replace trifling mechanical loss) was used at one refinery for the production of over 7000 tons of refined wax of the same excellent quality and standard colour obtained when using only fresh floridin. With fresh floridin a smaller percentage is required, and therefore less naphtha is needed for its recovery, with its unavoidable loss in the use of such a volatile solvent, but with floridin ranging in price from £2 to £20 per ton, with naphtha at 1s. 7d. per gallon, or with naphtha costing from 6d. to 3s. per gallon, with floridin at £13 per ton, the total cost of decolorising wax with recovered floridin is always less than when original floridin only is used.

A mineral named Bauxite, well known as a source of aluminium and its compounds, has been employed to a considerable extent for decolorising wax derived from petroleum, as well as for the partial removal of the sulphur from some petroleum products, but this material is not so efficient when applied to shale products, and possesses certain disadvantages which do not attach to the use of floridin, although it is less costly, ton for ton, than the latter.

While there has recently been a tendency to eliminate the use of acid in the refining of some petroleums, it must be borne in mind that the same inducement does not apply to the refining of oil-shale in Scotland, where much of the acid is utilised in the manufacture of sulphate of ammonia, a profitable undertaking, and where the acid tar is conveniently dealt with and employed as fuel in the dis-

tillation process: moreover, many petroleums are much more readily refined, with minimum loss, by means of the methods more recently adopted or suggested, than is the case with shale oil.

Note.—The Figures in this paper, illustrating the process, are to be considered merely as diagrams, and not as actual drawings of the plant.

As an introduction to the above paper on "The Refining of Oil-Shale" many iantern illustrations were exhibited, showing the development of the shale retort in the Scottish Shale Oil Industry, from the simple horizontal retort originally used in 1851 to the modern type employed at the present time, along with reproductions, from the original specifications, of numerous patented designs and modifications, proposed in this country and in the United States of America, over the whole period of the last 73 years, including the Crozier retort of 1923.

The revival of former designs was noted, the principles of the various types of retort were compared, and the claims made for some of these were subjected to criticism.

DISCUSSION.

Dr. J. A. L. Henderson asked how many of the American retorts to which the author had referred had proved of practical value.

Mr. Alfred W. Nash said that the Petroleum Department of the Birmingham University was greatly interested in shale, and the paper had been read there with much interest.

To his (Mr. Nash's) mind four points were brought out in the paper. In the first place the refining of shale oil appeared to be fraught with many difficulties which did not arise in the refining of free oil or petroleum. Secondly, heavy losses seemed to be incurred in the refining of shale oils as compared with petroleum. Thirdly, the capital cost and the refining cost per ton of oil appeared to be considerably heavier. And, fourthly, recent improvements in refining did not appear to have been adopted in the shale industry, possibly for very good reasons.

One point he should like to raise was whether they were doing right when comparing one shale with another, in view of the fact that they were now taking a little more interest in the potential value of oil-shale as a means of providing liquid fuel, in expressing

the yield of oil as so many gallons per ton of shale. This had been brought home to him by the fact that he had some shale in his laboratory which had a specific gravity of 2·8.

The Scottish shales had a specific gravity of about 1·75, and the Norfolk shales 1·3 he believed. In view of this wide variation, he would ask the author whether he would agree that the yield per cubic ton was not a better method of expressing the comparative values of different oil shales. The throughput of a retort depended upon the bulk of shale it held and not the weight of shale.

He noticed that a comparison had been made between the chemical constituents of shale oil and free oil, but no mention had been made of the higher sulphur content usually found in shale oil.

For instance, Norfolk shale oil contained as much as 9 per cent. of sulphur, which necessitated about 20 per cent. of the oil being taken out in the form of sulphur compounds. He believed the percentage of sulphur in Scotch shale oil was considerably lower, and perhaps the author would say what the exact figures were and what they represented in refining loss.

In table A two sets of figures were given as the yields for two different retort temperatures. Whilst these figures were of interest they conveyed little information, and he would ask the lecturer to be good enough to say what the temperatures were and what the total yields of oil per ton were under these conditions.

The second result under table B was doubtless obtained by cracking, and the iodine value and loss to sulphuric acid of the burning oil previous to refining would make interesting reading. Also the results given under table C would have conveyed more information had the retorting conditions referred to been given, and it would be interesting to hear whether these represented temperature conditions only or otherwise.

A reference had been made to the use of steam in driving out the oil vapours rapidly from the lower highly heated zone of the retort. He was not quite clear on this, but he gathered that even after passing the iron portion of the retort the shale still held its kerogen, which was not decomposed until it reached the higher temperatures. Perhaps the author would be good enough to confirm or correct that impression

No mention was made in that portion of the paper dealing with the refinery, of the use of residue or distillate heaters, and he concluded they were not used. If such were the case an idea of the thermal efficiency of the plant would be of interest.

Reference had been made to the cracking of crude distillate for the extraction of wax. The author had stated that pot stills were not absolutely necessary, and he had therefore wondered why pot stills were used at all in this particular case. He would have

thought that the ordinary boiler still, without steam, would have given sufficient cracking without using pot stills. With reference to the question of the difficulty of distilling heavy lubricating oil, the same trouble arose there as occurred when treating ordinary petroleum for this product, and he had been wondering why the high vacuum method of refining was not used in the method of distillation for heavy lubricating oils, in view of the fact that the advantages of the barometric condenser were already known in connection with the author's sulphate of ammonia plant. From his own experience, no matter how carefully the open steam and firing were regulated, he was convinced the results would not be so good as with a high vacuum.

The author had mentioned that the reason sulphuric acid was used in the refining process was because the excess acid was used in the sulphate recovery plant. He did not quite see the economy of that if another method of refining were used.

He supposed the acid was the same price no matter how it was used, and he did not see how that reason quite held. He supposed that shale oil was more or less a cracked product containing a higher percentage of unsaturated compounds than were found in free oil, and very careful refining was necessary. He was therefore a little surprised to see, in view of the fact that physical means of refining were used in the paraffix wax department, that they were not used in the other refining plant, especially bearing in mind that the acid treatment was very wasteful at all times, and he would say more so with shale oil. He desired to mention an experience he recently had had with some very highly cracked oil which showed a loss to sulphuric acid of 54 per cent. He had tried all methods of refining, both those in general use and patented methods, without result; but by using one of the physical methods (he would not mention the name of the adsorbent used because it was a proprietary article) he had reduced the loss to just over 20 per cent. and obtained a perfectly water-white petrol.

He was wondering whether the author would agree with him that the physical method would pay better than the sulphuric acid method of refining.

Mr. C. Albu asked whether the author found that the retorts he had described treated the Nova Scotia and other shales with equal ease with which they treated the Scotch shales, or whether he found more difficulty was experienced in treating them.

Mr. E. M. Bailey, in reply, said it was difficult to answer the questions that had been asked, because he knew considerably less about shale problems now than he thought he did 35 years ago. A cynic had remarked that everybody always had something to learn, even the youngest. He had been asked how many American

retorts had proved of practical value. If the meeting had had the advantage of the presence of a delegate from America that question might have been put to him. But personally he had been in touch with some concerns in America which had kept him informed of retorting in that country, and he gathered from one or two sources that none of them had proved of practical value yet in the sense that they were producing large quantities of oil. America must be given time in which to develop her shale resources. A tremendous amount of valuable work was being done in that country on the subject, much more valuable from a scientific point of view than anything that had been done in Scotland. So far as he was able to learn the Brown retort had certainly the biggest output—200 to 250 tons a day from one retort. A retort was rather a delicate instrument to handle, and a bench of retorts could easily be spoiled by bad handling. A case of that kind occurred in Australia, in which a type of retort he knew well was put up a good many years ago, and the whole bench of retorts was burned out in a far shorter space of time than was the case in Scotland. Nevertheless, those retorts could be handled particularly well with that type of shale, although with only about half the throughput. A remark had been made about recent improvements in refining not being put into practice. The reason for that was that a great many new methods of refining had been tried, but unfortunately they did not apply to the Scotch product as they did to petroleum. They had tried methods of filtration through decolorising material, and they had used chemical agents like hypochlorite of sodium, but none of them had the same effect in removing colour and smell that they had with a crude petroleum. A shale oil was of a very different character and quality.

With regard to the question of the use of the cubic or the weight ton, he differed from Mr. Nash, who seemed to advocate the recording of results on the cubic ton. It was quite true that the two were very misleading, but while Mr. Nash would no doubt suspect anyone who gave a figure on the weight ton, he (Mr. Bailey) was suspicious of recording results on the cubic ton, so that he thought the one equation balanced the other. It certainly ought to be stated which one was meant. In reply to the next question, the amount of sulphur in the crude oils ran from anything between about 0·8 to about 1·25 per cent. With regard to the temperatures of the low and the high specific gravity oils that were given, and the question that had been asked whether the oil was mostly distilled off in the iron portion of the retort or in the fireclay part, reference to Fig. 1 would indicate that the oil really only began to come off at the bottom of the metal. The temperature of 480° F. was recorded inside the metal part, and at that temperature the crude oil was only beginning to be evolved—*i.e.*, the whole of the hopper

on the top of the metal part of the retort was found to act practically as a pre-heater, and it was only when the shale began to travel down through the brick portion that rapid evolution of the oil commenced.

With regard to Mr. Nash's question on table B, as to the amount of the loss to sulphuric acid when the yield of the burning oil was 16 per cent., the burning oil in that instance was refined ordinary paraffin burning oil for lamps: 89 per cent. of products was obtained, giving 16 per cent. of refined burning oil, 10 per cent. of thoroughly refined naphtha, 9 per cent. of fully refined wax, and 54 per cent. of crude fuel oil. The idea was to maintain all the valuable products—wax, burning oil, and naphtha ready for the market, but to increase the yield of Admiralty fuel oil from something like 25 to 54 or 71 per cent. They succeeded in doing that with one distillation of the crude oil, cracking the later fractions, and then extracting the solid wax from the heavy part of the distillate, taking the spirit and the light-burning oil and refining it in the usual way with the finished products, the loss in refining being comparatively trifling even with the shale oil. It was only when the heavier products were dealt with that the losses to acid were very high. He was sorry he could not give any data with regard to the thermal efficiency of the distillation plant. With regard to cracking in the boiler still and high vacuum distillation, he understood that in America they could carry the distillation of crude petroleum down to coke—*i.e.*, the production of coke in large horizontal boiler-stills. There was a good deal of shale dust and grit as well as carbonaceous matter in Scottish shale oil, and if they carried it to dryness in a boiler-still, coking on the boiler plates was apt to occur, which resulted in over-heating and possible danger. They had therefore always made a point of carrying on distillation to dryness in the production of coke in a pot still. With regard to high vacuum distillation, they were waiting until someone successfully distilled crude oil in a vacuum on a large economic scale. It was done in the production of the residue of motor fuel oils, and so on, in working up residues on a small scale, but as far as he knew there had been no large scale satisfactory working on vacuum distillation of oil. The question of using a vacuum exhaust for the evaporation of a liquid containing sulphate of ammonia was a different problem. That was simply a question of evaporation, and as regards the economy of using recovered acid from the refining of the crude oil for sulphate of ammonia, he might not have put it very correctly, but what he wanted to indicate was that they used something like 18½ cwt. of acid for producing a ton of sulphate of ammonia, and instead of buying that they used the final tar, recovered the acid from it, and used that recovered acid for the manufacture of the ammonia. It was necessary to

use all the original acid of a certain high strength to obtain satisfactory results in the refining of oil; and after removing the recovered acid they burned the tar, which saved them from buying coal, so that there was a considerable economy—*i.e.*, it paid to have a good deal of ammonia from the shale along with the oil rather than to have a great deal more oil and less ammonia. There was a certain proportion of oil to ammonia which gave the best economic result. Everyone would agree that the physical methods were better than treatment with sulphuric acid, but difficulties existed in carrying them out. He had had no experience of the Nova Scotia shale, but the New Brunswick shale was quite as easily retorted as the Scottish shale.

He desired to say, in conclusion, that in working the large scale experimental retort with shale from different parts of the world, he had not found any one that gave as pure a crude oil as the Scottish shales. That was a problem for the geologists to discuss. He had examined oils produced in their own retorts from shales obtained in various parts of the world. Many of the shales had given a much larger yield of oil. One of the shales from New Brunswick had given both a larger yield of oil and almost as large a yield of sulphate as any shale, but none of them had given oil exactly of the same value per gallon of crude oil as the Scottish shale. There were a great many problems awaiting the development of shale oil.

On the motion of the Chairman, a hearty vote of thanks was accorded to the author for his interesting paper, and the meeting adjourned.

Mr. R. H. Crozier wrote:—

I have read Mr. Bailey's paper on "The Refining of Oil-Shale" with very much interest, and should particularly like to thank the author for this contribution to the technology of shale treatment which brings our knowledge of the Scottish methods up-to-date.

Mr. Bailey in his paper mentions the Burma shale, a parcel of which was treated at the Pumpherston works last year. I have been intimately associated with the development of this Burmese deposit for the past three years, and it has occurred to me that some particulars regarding the deposit and its prospective development may be of interest to members of the Congress.

The deposit, which is of fresh-water origin, lies in the valley of the Thaungyin river, near the Siamese border, some 60 miles E.N.E. from the port of Moulmein. The particular concession on which most of the work has so far been done, comprises an area of 32 square miles, of which some 22 square miles is underlain by the shale basin.

The main seam of the series, between 6 ft. and 7 ft. in thickness,

outcrops on the Eastern rim of the basin for a distance of approximately 5 miles. The seam has a general strike to the North and an average dip of 12° to the West.

One-half square mile of the area has been bored by means of Calyx core drills and proved to contain 13,500,000 tons of shale of an average grade of 33 gallons per ton. Of this tonnage some 7,500,000 tons exists in the main seam already referred to, the average analysis of the bore cores of which indicates an oil content of 45 gallons per ton. It is interesting to compare this figure with the 44 gallons per ton, which resulted from the treatment of the bulk parcel from this seam at Pumpherston.

In connection with the work on this shale deposit a new type of retort has been developed which promises to materially improve the position with regard to the economic production of shale oil. In this retort the heat is conducted to the centre of the descending shale column by means of internal heating flues which traverse the apparatus diagonally. These flues, which are arranged in vertical and horizontal series, permit of the retort being extended to handle several hundreds of tons of material per day in a single unit. The retort is also designed to take advantage of the first fractionation of the oil direct from the shale in the process of retorting. This fractionation is, of course, not commercially effective and varies considerably according to the character of the shale under treatment, but by adapting the retort to a counter-current cascade condenser, it is possible to produce an effective fractionation direct from the shale in one operation and to effect a considerable reduction in refining costs.

The patents for the retort and the condensing apparatus have been acquired by Mineral Oils Extraction, Ltd., which company is erecting a 10-ton testing plant for demonstration purposes in the grounds of the Burma Section at the British Empire Exhibition.

Thursday, June 5th, 1924, at 2 p.m.

MR. ARTHUR W. EASTLAKE, M.I.Min.E., A.M.I.Mech.E., Vice-President and Honorary Secretary of the Institution of Petroleum Technologists, in the Chair.

The Chairman said it required no words of his to introduce the reader of the first paper that afternoon, namely, Mr. Barringer, the President of the Institution of Petroleum Technologists and a leading expert in the designing and fitting of tank steamers.

Oil Transport: The Oil Tank Ship.

By HERBERT BARRINGER, M.Inst.C.E., M.I.Mech.E., M.I.N.A., M.Inst.Mar.Eng., President of the Institution of Petroleum Technologists.

BEFORE proceeding with a description of the modern Oil Tanker it may be of interest to briefly allude to the earlier transport of oil, and to set out the different stages of development which have led to the adoption of the present design.

In no other branch of commercial transport has there been such a radical change as that which was inaugurated by the introduction of the bulk oil carrier.

Previously practically the whole of the transport of oil had been carried out by the employment of wooden barrels and of tins contained in wooden cases, the contents of the latter being generally described as case oil. The advent of the bulk oil carrier practically abolished this method of transport, and enabled cargoes to be loaded and discharged more expeditiously, at the same time saving the expense of the package. Moreover, in a barrel cargo about a sixth of the total weight was represented by the barrels alone.

There is no written history of the earliest bulk oil carrier, but the Chinese Newchwang junk, built for the carriage of water in bulk, and afterwards used for oil, must be amongst the earliest examples of this class of vessel. It was provided with an expansion trunk, the object of which, as in the modern steamer, being to allow for expansion of oil by rise of temperature, and also to keep the main hold always full, the wash of water or oil from the movement of the vessel being confined to a limited space about a third of the beam.

There is a record that special instructions were issued as to the carriage of oil up the Volga about 1723, and in 1754 the Persians collected oil on Holy Island, near Baku, and conveyed it in sailing

vessels, evidently in bulk, as it is mentioned that sometimes the sea was covered with oil for leagues, owing to the leaky state of these vessels.

It is curious to note that in the early days wooden barges were employed on the Volga to carry oil in bulk, direct to the skin of the vessel, but great difficulty was experienced in keeping these tight, and considerable losses from leakage were experienced. An interesting method was adopted to reduce this loss, and consisted in loading the barges, when full of oil, with a deck load of stones. This gave the barge a greater draught, and thereby caused the pressure of water outside to be greater than the pressure of the oil inside, the balance of pressure being in favour of water entering the barge, instead of oil leaking out, and as the decks were kept low, and the hatches were made oil-tight, this did not allow much water to enter.

In 1875 the first organised attempt to transport petroleum in bulk, without the use of tanks, was made by Nobel on the Caspian. He appears to have loaded a wooden barge with residuum, and despatched it from Baku to Astrakan, the venture being successful. But it was not until 1878 that the first steamship, the *Zoroaster*, was adapted for carrying oil in bulk. At first tanks were fitted in the holds, but later on these were removed, and the oil carried to the skin of the ship. It is interesting to note, in connection with some modern vessels, to be mentioned later, that these tanks were cylindrical in form, and placed in a vertical position. During the next ten years over thirty steamers were commissioned for carrying petroleum in bulk on the Caspian, and there is now a very large fleet of steamers engaged in this trade, all burning liquid fuel.

In 1860 America commenced to ship oil to this country in small quantities, practically samples; and it was not until twenty-six years later that Russia commenced to export oil to Great Britain. The first cargo shipped from America was by the brig *Elizabeth Watts*, of 224 tons, this cargo being safely delivered in London about the end of 1861.

Probably the first vessel designed and built in this country for the carriage of petroleum in bulk was the iron sailing vessel *Atlantic*, launched from Messrs. Rogerson's yard, St. Peter's-on-Tyne, in 1863. Her dimensions were 148 ft. in length with 28 ft. 6 in. beam, and a depth of 16 ft. 9 in. This vessel appears to have been fitted with sheet-iron bulkheads, dividing the hold into compartments, and acting as washplates. Unfortunately, no records of her career have been found. The pioneer tank steamer built in this country appears to have been the *Vaderland*, 2,748 tons, launched in 1872 from Messrs. Palmer's yard at Jarrow-on-Tyne. She was fitted with a space of 20 to 26 inches between the tanks and the shell of the vessel, trunkways being carried up to the level

of the upper deck. This vessel was fitted with passenger accommodation, but there is no record that a cargo of oil was ever loaded in her, or in the two sister ships *Nederland* and *Switzerland*, built in 1873 and 1874 respectively. It is generally supposed that the owners were afraid that passenger bookings would be affected if it were known that the ship was carrying petroleum, and it is believed that the tanks were used for water ballast only. Although it may be claimed that these were the first oil-tank steamers built in this country, they did not solve the problem of the satisfactory carriage of petroleum in bulk.

It may be well at this stage briefly to mention the steps by which the modern tanker has been evolved. These may be stated as follows :—

(1) The introduction of longitudinal and transverse bulkheads. The functions performed by these structures consist in the former, of reducing by half the difference in level of oil due to rolling, or listing of the vessel, thereby preserving the stability of the ship, and, in the latter, in reducing the length in which the oil can surge when the vessel is pitching in a seaway. The longitudinal bulkhead was at first only fitted as a divisional washplate, but is now made oiltight, and of a strength to support the pressure of the total head of oil on either side.

(2) The fitting of expansion trunkways. These are of a reduced breadth, generally being about a third of the beam of the vessel. The longitudinal bulkhead being carried up to the top of the trunks further reduces the difference in levels of oil due to rolling or listing of the ship, and also provides for the expansion or contraction of the oil by variations in temperature. For this purpose 2 per cent. of cargo capacity is generally allowed. The level of the oil in the trunkways should never be allowed to fall below that of the deck. The introduction of the longitudinal bulkheads reduces by one-quarter the loss of metacentric height due to movement of the oil.

(3) The provision of cofferdams forward and aft of cargo tanks. These consist of spaces generally about 4 ft. in length usually kept empty, and forming a partition between the tanks and the engine and boiler rooms aft, and a similar protection between the cargo tanks and the forehold and the deep tank forward, any leakage from bulkheads being collected in these spaces.

(4) The carriage of oil direct to the skin of the vessel without the use of independent tanks. The fitting of separate tanks with their connections had proved a fruitful cause of trouble from leakage and also provided confined spaces in which gas could accumulate, and become a source of danger.

(5) The abolition of the cellular water-ballast double-bottom below the cargo tanks. In vessels fitted in the old way, there was

always a difficulty in keeping the top of the ballast tank tight, and one accident at least is on record as due to oil having found its way from the cargo tank into the double bottom.

(6) The building of pump rooms extending the whole breadth of the vessel, and carried down to the bottom plating of the ship and up to the upper deck. This method, when the pump room is placed amidships, furnishes another cofferdam, dividing the cargo tanks into two distinct portions, and when two pump rooms are fitted, as in large vessels, the cargo tanks can be divided into three separate groups, affording greater safety from danger of mixing by leakage through bulkhead when different classes of oil are carried ; the pumps can also be placed at the lowest position in vessel, thus facilitating the drainage of the tanks.

(7) The fitting of compound hatches, to deal with the carriage of cargo other than a liquid one. A larger hatch is provided furnished with a bolted cover carrying the ordinary oiltight hatch, the whole being removable when a larger opening is required.

(8) The perfection and elaboration of the pumping arrangements. Double lines of suction pipes extend the whole length of the cargo tanks, and carry two suctions on each pipeline on each side of the longitudinal bulkhead in each main tank, one on each pipeline passing through longitudinal bulkhead whereby oil can be transferred from any one tank to another, and different classes of oil can be discharged without mixing in pipelines. The suctions are arranged so that the ship can draw from barges alongside with her own pumps. Several discharges are provided in various positions on deck, including lines for the discharge over the stern, and bow if required in port, or for the transfer of oil at sea to another vessel.

(9) The fitting of mechanical ventilation to tanks.

(10) The fitting of steam-heating coils in the cargo tanks. With the introduction of liquid fuel, and heavy viscous classes of oil, etc., it was found impossible to handle these expeditiously at ordinary temperatures ; it, therefore, became necessary to provide means for heating cargoes in the tanks, a temperature of upwards of 120 deg. Fahr., or more, being required in some cases.

(11) The introduction of liquid fuel in place of coal for the firing of the steam boilers. This required all bunkers to be constructed oil-tight, and the introduction of pumps, etc., for handling the oil, with special arrangements when low-flash oil is used as fuel.

In 1886 was launched the first tank steamer of the type, which has been since followed with some modifications and exceptions. She was built by Messrs. Armstrong's, to the designs of the late Colonel H. J. Swan, and named the *Glückauf*. She was a vessel of 2,307 tons gross register, 300 ft. in length by 37 ft. beam by 24 ft. depth, with a speed of about 11 knots.

Colonel Swan's design may be described shortly as follows: The hull of the vessel was divided into compartments by transverse bulkheads, these compartments being again divided longitudinally by a central bulkhead, which extended through all the oil spaces. A pump-room was provided aft, which extended right across the vessel, and formed a cofferdam, or safety space, dividing the stokehold from the oil compartments. Between the main and upper decks a narrowed trunk was arranged, the trunkway extending the whole length of the cargo tanks. The transverse and longitudinal bulkheads being carried up to level of the upper deck, this arrangement allowed for expansion of oil from any rise in temperature and by keeping the greater portion of the tank below the main deck full reduced the danger of movement of oil from rolling and pitching of the vessel, also providing spaces along the whole length of the vessel on each side of the trunkway for the accommodation of light oil cargoes and bunkers. The bulkheads were designed to stand the pressure of the full head of oil when one tank was full and the next one empty. A double bottom was fitted for water ballast under the machinery space and in the forehold only. The machinery and boilers were placed aft, no tunnel for shafting being required.

The expansion trunkways in this vessel were much narrower than those now generally fitted being only 4 ft. 6 in. wide on each side of the longitudinal bulkhead. She was fitted with a very long poop, the bunkers being accommodated under this deck and entirely above the upper deck; the spaces alongside the expansion trunks were not utilised for this purpose, but a portion of this space was designed to carry oil. Electric light was fitted throughout.

Various tank steamers now began to be built, amongst which the following may be mentioned:—

In 1885 the *Sviet*, built in Gothenburg for the Russian Steam Navigation Co., of Odessa; 1,474 tons net reg., fitted with tanks, and in no part was oil carried to the skin of the ship. In 1886 the *Bakiun*, built by Messrs Gray, of Hartlepool, to the order of Mr. Alfred Suart. This vessel was the first British-built and owned tank steamer.

Messrs. Alfred Suart and Co. converted five ordinary cargo ships into oil-carrying vessels, and in addition between 1886-1892 built and managed eleven other bulk oil steamers.

The year 1888 was specially notable for the activity displayed in the building of new tank steamers. Messrs. Armstrong's alone put out twelve ships. The Anglo-American Oil Company also made its first appearance in London, and commenced the purchase and building of bulk oil carriers. The first two vessels built to their order were the *Manhattan* and *Bayonne*, and these were followed by many notable ships. The *Naragansett*, the largest of their

fleet at the time, was built by Messrs. Scott, of Greenock, in 1903. In this vessel the machinery and boilers were placed amidships, the screw shafting being carried through an oil-tight tube passing through the after-oil compartments, this tunnel was entered from two points by trunkways carried up to the shelter deck. At the time it was considered that a vessel of this size would not prove satisfactory if the engines were placed aft, partly on account of structural questions and partly as to difficulty in trim under working conditions.

These fears have since proved to be groundless, vessels of 18,000 tons D.W. having been built, and having done excellent work with the machinery and boilers in the after position, the advantage being obvious and the cost of construction less.

The *Narragansett* was a vessel of 512 ft. in length, 63 ft. 4 in. beam and 32 ft. 6 in. in depth, with a capacity of 11,000 tons of oil and 1,500 tons of fuel, either coal or oil, in bunkers, her average speed at sea being about 11 knots. At the time of being put into commission she was undoubtedly the finest oil-tank steamer ever built.

Another notable vessel owned by this company is the *Iroquois*, built by Messrs. Harland and Wolff, of Belfast, in 1907. She was the first tank steamer to be fitted with twin-screws, engines placed aft. She was specially designed to tow a large sea-going oil barge, the *Navahoe*, built at the same time for carrying oil across the Atlantic, and has made numerous voyages under these conditions, averaging a speed of about 10¾ knots and delivering 18,000 tons of oil, including the contents of the barge. This so-called barge is a vessel of 450 ft. in length by 58 ft. 3 in. beam by 31 ft. 2 in. in depth, with a gross tonnage of 7,718, and is rigged as a schooner. She is fitted with a steam boiler and set of pumps in order to deal with her own cargo. A special winch is provided for towing purposes. The towing wire, instead of being firmly secured, is wound round the drum of a winch which is so arranged that, upon an extra strain on the tow-line, the winch immediately pays out cable, and on strain being relaxed, again picks up the slack; owing to this device it is very rarely that a cable is broken. A similar winch is fitted on barge and two tow-lines are generally used at sea. This method of transport is adopted to a large extent on the American coast.

Closely following the Anglo-American Oil Company, came the Shell Transport and Trading Company, with many vessels, their object being to open up the Eastern trade, and to carry petroleum in bulk through the Suez Canal, which up to that time had not been allowed. The *Murex* was the pioneer vessel of the fleet, built in Hartlepool in 1892, and was the first vessel to pass through the Suez Canal with a cargo of oil in bulk. The vessels of this

Company were the pioneers in the matter of carrying dual cargoes, and many voyages to the East were made, carrying a cargo of Russian oil outwards and returning with a perishable general cargo.

These vessels were also among the first ocean-going British vessels to adopt oil as fuel in place of coal, the oil being atomized by a steam jet, and sprayed into the furnaces, a burner patented by Messrs. Rusden Eeles being used.

In 1899 the Burmah Oil Company started their fleet of bulk oil carrying steamers, designed to trade entirely abroad, and distribute the Company's oil around the Indian Coast. Six vessels were built, and although not large vessels they were at the time the most complete in their pumping arrangements of any vessel afloat.

Among the first private oil tank steamship owners, Messrs. C. T. Bowring & Co., Ltd., of Liverpool, must be included—their first vessel, the *Bear Creek*, being built by Messrs. Armstrong's as early as 1890; since which date they have built numerous vessels, and still keep well to the front with their fleet of oil carriers, the greater number being fitted for the burning of oil fuel. They suffered severely during the War, having lost no less than five vessels by torpedo attack, and in addition had one vessel twice torpedoed, but surviving, was ultimately repaired and is now in commission.

In 1906 Lord Cowdray placed an order for a vessel of 2,041 gross tonnage, the first of the large fleet of tank steamers owned by The Eagle Oil Transport Company. Others followed of 5,251 and 6,220 tons, and in 1913 the largest order ever placed at one time for tank steamers was given out, being for ten vessels of 15,000 tons D.W. and seven of 9,500 D.W., a total of 216,500 tons deadweight carrying capacity, and a gross tonnage of 133,384. These 15,000 tonners were the largest tankers afloat, but the Company have now tankers of 18,000 tons running, fitted with double reduction geared turbines.

Before dealing with a few points, some of them novel, contained in these vessels, it should be stated that all but the first few are constructed on the Isherwood principle of longitudinal framing, the first oil tank steamer built on this principle having been the *Paul Paix* in 1908.

The Isherwood design consists of longitudinal frames fitted between transverses and bulkheads instead of the ordinary transverse framing. This arrangement lends itself admirably to the requirements of tank vessels, especially as regards good, and distributed attachments to the bulkheads, and there is also a saving in weight of hull and an increase in strength over the ordinary transverse system. The Miller design has also been used in several vessels. This consists of longitudinal framing at bottom of vessels

and under decks connected by vertical frames at sides—this does away with the ledges formed by the longitudinals at sides of vessel and it is claimed is as strong, and also allows of a saving in weight.

It may here be mentioned that special care is required in the design and construction of vessels carrying oil in bulk direct to the skin of the ship. The rivetting is required to be of a closer pitch than that used in ordinary vessels; absolute fairness of holes and close inspection of workmanship is necessary to ensure oil-tight work. All cargo tanks, and liquid fuel bunkers must be subjected to severe water tests before the launching of the vessel, these tests alone generally occupying a period of from four to five weeks.

A general description of one of the large modern Oil Tankers may here be introduced, which may be taken as representing the general type of vessel used in the bulk transport of oil.

The large 15,000 ton vessels are 548 ft. in length, 66 ft. 6 in. beam and 41 ft. 6 in. in depth, and of the two-deck and shelter deck type. They are divided into a cross bunker, and 12 cargo tanks by transverse bulkheads, and these are again divided by an oil-tight longitudinal bulkhead, extending the whole length of the trunks, and sub-dividing the cargo space into 24 compartments. The spaces alongside the expansion trunkways can also be utilized for cargo if required. There is a cofferdam at each end of the cargo space. Two pump rooms are provided, carried to the bottom of the vessel, which also form cofferdams, and divide the cargo space into three distinct portions; in all there are 20 bulkheads, and the cargo tanks have a capacity of about 3,500,000 gallons. A double bottom is fitted under the boilers, and a deep tank forward of cargo holds, which, together with fore and after peaks, are utilized for ballasting, and trimming the ship.

The liquid fuel bunkers are arranged in a large cross bunker, immediately forward of the cofferdam, and alongside expansion trunkways with trunks carried up through the shelter deck, and fitted with screw-down hatches. They will accommodate 4,100 tons of oil, and as no fuel or cargo is carried aft of the after cofferdam, the machinery and boiler spaces are entirely cut off from cargo, and fuel. Liqued fuel can also be carried, if required, in the forward deep tank. A large pump is fitted forward for dealing with bunker oil. Some of these vessels are also adapted for burning coal, the bunkers being carried under the shelter deck and entirely distinct from the oil fuel spaces. The whole of the bunker and cargo spaces are fitted with coils of 2 in. piping, through which steam can be passed to deal with heavy viscous oils, which require heating before they can be satisfactorily pumped. Each compartment can be heated separately. About 8,000 ft. of this piping is fitted, providing in the cargo tanks a square foot of heating surface per 2·7 tons of oil. Special arrangements are made for the testing, and

filtration of condensed water coming from these coils before it is returned to the boilers, to avoid the possibility of oil entering the latter through a leak in the tubing.

The White system of heating cargo is also sometimes employed. This consists of circulating the oil through separate heaters where the oil is warmed and passes back to tanks. By this arrangement the quantity of piping is reduced.

A feature worthy of notice is the large pumping installation, by which different classes of oil can be handled in every conceivable manner. It consists of four duplex pumps, two in each pump room, and each having two 22 in. steam cylinders and 14 in. oil cylinders, with a stroke of 18 ins. The capacity of each pump is 300 tons per hour. They are designed to deliver oil against a pressure of 250 lbs. per sq. in., and have in practice discharged 15,200 tons of liquid fuel in 31¾ hours through one 14 in. shore line. The main suction pipes, of which there are two distinct lines, are of 14 ins. diameter, with four cross-over suctions in each main tank (48 in all), each provided with a straightway valve operated by a rod from deck; there are nine discharges on deck with derricks to trim them for handling hoses. In order to utilise this large pumping power, facilities in the way of pipe lines leading to storage tanks ashore have been provided, an advance since the first shore installations, when one 6 in. line was deemed sufficient.

All the cargo tanks are provided with large compound hatches, so that in the event of its being required to carry a cargo other than a liquid one, the large hatch cover, which carries the smaller oil-tight lid can be removed, thus affording a loading space of 9 ft. by 10 ft.

Gas freeing pipes are also fitted to each tank and carried up masts in order to allow gas to escape should same by rise in temperature cause undue pressure; also when loading or discharging spirit cargo with hatches closed. These allow the air to escape or enter. It is usual to fit valves on these pipes, which are spring or dead weight loaded, and open either to vacuum or pressure; these avoid the unnecessary loss of vapour and do not open until an arranged pressure accumulates.

A large ventilating fan is fitted in the aft pump room, which is arranged to draw air from, or discharge it into tanks (when empty) to clear them of gas. The air is drawn or discharged through the main suction lines, but as the strums are necessarily fitted close to the bottom of the vessel, special air valves are bolted on the sides of the strums 12 ins. from the bottom of the ship, in order to obtain a clear passage for the air in the event of any oil being left in the bottom of the tanks, which might possibly seal the mouth of the strum, or at any rate obstruct the area of the inlet. There are forty-eight of these air valves all operated from the deck. In many cases steam air injectors are employed in place of fans.

In addition to the ventilating fan, it is necessary to provide means for introducing steam to tanks for the purpose of assisting in the cleaning and for the expulsion of gas. Steam connections are therefore arranged, so that the tanks can be filled with steam. These connections can also be used as fire extinguishers if required. Redwood gas detectors are also provided, by means of which the presence of, or freedom from, gas in the tanks can be ascertained.

The whole of the vessel is of course lighted electrically. All lamps in the pump rooms are doubled-globed and no fuses or switches are fitted there. A steam steering gear of the Wilson Pirrie type, acting directly on the tiller, is fitted aft, with telemotor control from the bridge.

These were the first vessels to be adapted for the burning of what is termed low-flash oil; that is to say, oil with a flash point below 150 deg., Lloyd's previously not allowing fuel of a lower flash point to be used. To overcome this difficulty special arrangements had to be made to satisfy the Classification Committee. It was found necessary to construct a gas-tight isolated chamber adjoining the stokehold, and extending from the bottom of the vessel to the shelter deck, with entrance only from a house built on this deck. This chamber contains all the pumps, heaters, strainers, etc., for dealing with the supply of liquid fuel to burners, all in duplicate.

The liquid fuel pumps for supplying burners are of special design, being simplex, and with long stroke, which has been proved the most satisfactory type for dealing with heavy oils. The steam cylinders of these pumps are jointed to the bulkhead and project into the stokehold, so that the cylinders, pistons, valves, etc., can be examined, and the stop valves operated from this position without entering the isolated chamber. The oil ends of the pumps, and all rods and glands are kept inside the chamber, in order that no gas can possibly escape to the stokehold. The oil pipes supplying the burners are jointed to the plating where passing through the bulkhead, and are kept above flooring and well in sight in order that, should a leakage occur, it can be immediately detected. A ventilating fan is fitted to this chamber, with the engine in the stokehold, and the driving shaft passing through a packed gland on the bulkhead. A steam lift is fitted in the chamber to convey attendants to and from deck. The lighting is provided from electric lamps in the stokehold through a heavy glass scuttle. It will therefore be seen that no gas can possibly reach the boiler fires, and, unless any adjustments are required, it is only necessary to enter the chamber in order to clean the filters.

The propelling machinery consists of a set of quadruple-expansion engines with cylinders 28½ ins. by 41 ins. by 58 ins. by 84 ins. in

diameter, having a stroke of 54 ins. They are supplied with steam by four cylindrical single-ended boilers 16 ft. 3 ins. diameter by 12 ft. in length, having four furnaces in each boiler, and working at a pressure of 220 lbs. per square inch, fitted for burning liquid fuel on the Howden-Wallsend forced-draught system, in which the oil is heated to a temperature of from 160 degs. to 200 degs. Fahr. (varying with the class of oil used), and then forced through burners at a pressure of about 150 lbs. per square inch, whereby it is atomised. A rotary motion is imparted to the oil in passing through the burner before it is discharged through a small orifice to the furnace. Air is supplied to the furnaces by a large fan at a pressure equal to a column of water about 2½ ins. in height at the fan, and is heated in the uptake before entering the furnaces. The air is directed by vanes fitted in the furnace fronts, which also impart a rotary motion.

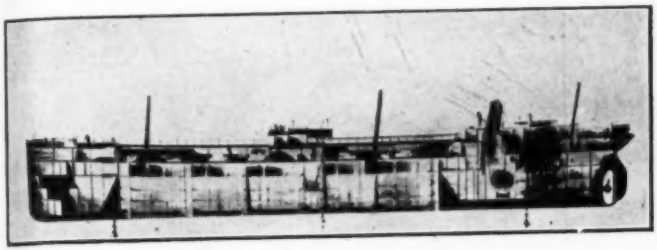
Three boilers are sufficient to maintain full speed at sea, the fourth being used for heating the cargo, if required. If this is not necessary, the boilers can be changed over and cleaned, one at a time, at sea, thus avoiding delay in port. These vessels attained a speed of 12 knots on trial, fully loaded.

The duties of officers and crew on tank steamers are specially onerous, and therefore particular attention has been paid to the accommodation. Electric fans are fitted in all cabins, and all doors, scuttles and ventilators are provided with mosquito-proof wire gauze. A Hall's CO_2 refrigerating machine is fitted in the engine room, with a chamber to contain meat, vegetables, and ice-pails for the use of the crew.

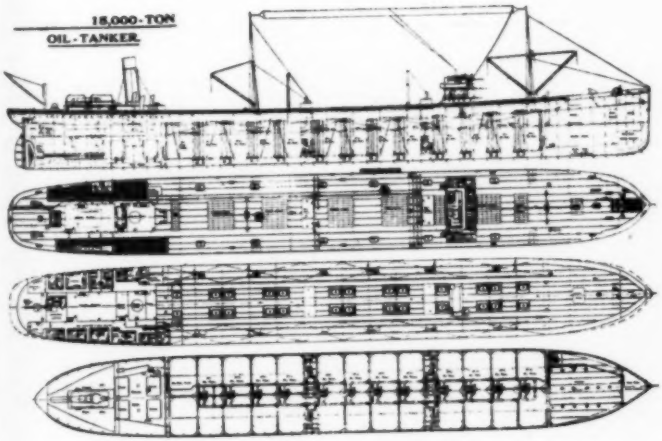
In 1914 an ordinary cargo vessel was fitted for an American firm with cylindrical tanks, placed horizontally in the holds, the idea being that, if required, these could be removed, and the vessel used as an ordinary cargo steamer. Three vessels of considerable interest were also built in 1914, the *Aztec*, *Brelford* and *Ricardo a Mestres*. These were designed with ordinary holds, having cellular bottoms, but are fitted with cylindrical tanks, standing vertically, and of nearly the same diameter as the beam of the vessel at the particular spot in which they are placed. They are connected with a trunkway on deck, and are attached to the sides of the vessel by webs, so that one half of the circle of each tank forms a semi-circular bulkhead across the vessel, the spaces between the tanks being utilised for accommodation of pumps, valves and pipes.

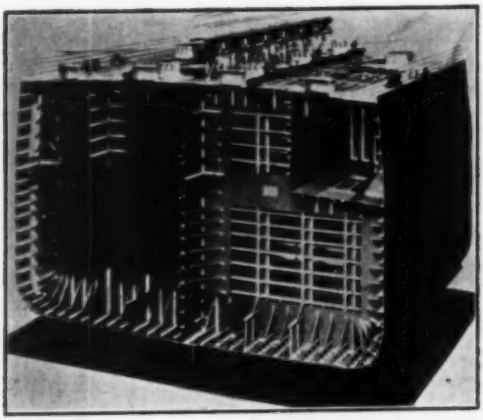
An oil-tight longitudinal division between the tanks is also provided. The expansion trunkways are also divided transversely at each tank, keeping them distinct.

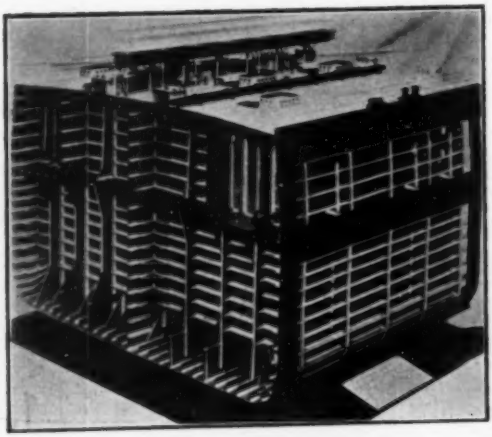
The top of the cellular bottom forms the bottoms of the cylindrical tanks. Oil can be carried in the cellular bottom, if required, and



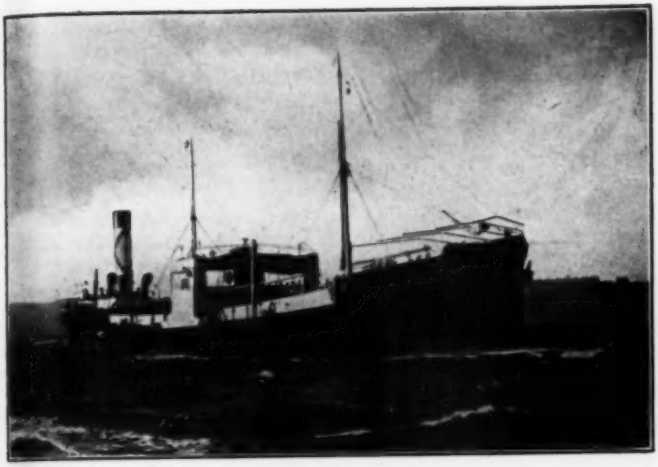
SECTIONAL MODEL TANK STEAMER.







THE ISHERWOOD CONSTRUCTION.



TANKERS AT SEA.

OIL FILTERS.

also in the spaces, of double concave section in plan, between the circular tanks. The advantages claimed are :—

(1) Easy conversion to ordinary cargo-carrier, if required.
(2) No oil-work riveting on the shell of the vessel, except on the bottoms in way of the cellular bottom, and a portion of the hull, if the spaces between tanks are used for cargo.
(3) No stiffening of bulkheads required, as in a flat surface. The stresses on all rivets in tanks are sheer.
(4) Slightly cheaper construction.
(5) Some saving in weight of hull.
(6) Each tank divided by a space from the next one, preventing any possibility of mixing of different classes of oil.
(7) All valves, pipes, etc., outside tanks, are always accessible.
(8) The cellular bottom provides space for water ballast under ordinary conditions, without using cargo tanks for water.
(9) When cargo requires heating, there is less loss by conduction through hull to sea-water, as there is an air space between the tank sides and the shell plating.
(10) Easier cleaning of tanks when required.

The general design will accommodate a full cargo of about 40 cubic ft. to the ton in the cylindrical tanks, and if a lighter cargo is shipped the cellular bottom can be utilised.

The principal objection to the design (and this must be considered a serious one) is the fact that there are a great number of spaces where gas may accumulate, and thus introduce an element of danger. This must be looked upon as a retrograde step, as the first principle of tanker design has been to do away with all spaces, as far as possible, where gas can lie, since it is well known that in some of the earlier vessels accidents occurred through an accumulation of gas in these confined spots. Moreover, there does not seem much probability of its being necessary to convert a tanker into an ordinary cargo vessel, now that the use of liquid fuel is becoming more general, and the world's output of petroleum is increasing. It has also been found in practice difficult to keep tanks tight, and it is unlikely that other vessels of this class will be built.

The internal-combustion engine is attracting more attention every year, and there have lately been marked improvements in design. The double-acting four-cycle being one of the developments, and the opposed piston type is also in favour with some builders. Several tankers have been fitted with internal-combustion engines, and are doing good work, but accurate data, in reference to upkeep, are difficult to obtain. Although there is no doubt as to the economy in consumption of fuel, it must be borne in mind that commercially there are several factors to be considered. In the

first place, the cost of Diesel engines is greatly in excess of that of steam machinery. This means that the initial cost of vessel is greatly increased. Insurance is proportionately heavier, and although the weight of fuel burnt is less, and therefore bunker requirements can be reduced, thus allowing vessel to carry extra deadweight, the cost of fuel is much higher, and although number of firemen is reduced, more greasers are required, and the engineering staff is larger than that required in the same powered steam-driven vessel. It is also usual to fit an auxiliary boiler to handle steering gear, windlass, winches, etc., and to supply steam for steaming out tanks and for heating cargo if of a heavy and viscous nature. In some cases, where possible, electricity is employed, but this again adds to first cost, and requires skilled attention. Consumption of lubricating oil is also heavy. It is not possible to speak definitely as to the cost of upkeep, but undoubtedly it will be heavier than with steam. All the above costs must be taken carefully into account before the question of commercial economy can be definitely settled. The reduction in weight and cost of the Diesel engine, together with larger powered units, is a question which demands close attention and experiment.

Vessels have been fitted with steam turbines using superheated steam running at high speed, and driving through double reduction gearing, the boilers being oil-fired. In some cases trouble has been experienced with the reduction gearing. Suitable material and extremely accurate cutting of teeth are essential to secure satisfactory running. There is little doubt that eventually, when mechanical difficulties have been overcome, probably the internal-combustion engine in some form will to a great extent displace the steam-operated machinery in tank vessels. The following table shows an approximate comparison between Diesel machinery, with electrical or steam auxiliaries and a triple expansion steam engine burning liquid fuel in boilers. It will be noted that interest, insurance, etc., on extra cost of Diesel machinery has not been taken into account.

COMPARISONS BETWEEN SULZER DIESEL ENGINES AND TRIPLE EXPANSION ENGINE FOR OIL TANKER (SEA SERVICE).

Vessel.—Length B.P. 440 ft. × 57 ft. 6 in. × 26 ft. 5 in. draft.

Engines.—Twin screw Diesel Engines, 3000 B.H.P. on trial, 2700 B.H.P. continuous on sea service.

Single screw Steam Engines. 3000 I.H.P. on trial, 2600 I.H.P. continuous on sea service.

Speed of vessel with Diesel Engines (2700 B.H.P.) continuous at sea, 10·625 knots.

Speed of vessel with Steam Engines (2600 I.H.P.) continuous at sea, 10·25 knots.

Basis of bunker capacity:

22 Days voyage for Diesel Engines at 10·625 knots.
23 do. do. Steam do. 10·25 „

	Sulzer Engine 4 S. 60 Elec. Aux.	Sulzer Engine 4 S. 60 Steam Aux.	Triple Exp. Steam Eng. Oil Fuel H.F.D.	Triple Exp. Steam Eng. Coal Fired H.F.D.
Total deadweight .. tons	10,150	10,150	10,300	10,300
Bunker capacity .. „	286	315	735	1,100
Stores, F.W. feed water, spares, etc. .. .. „	120	140	200	200
Cargo deadweight .. „	9,744	9,695	9,265	9,000
„ capacity .. .. cu. ft.	490,000	490,000	500,000	500,000
„ density	50·5	50·6	54	55·5
	£	£	£	£
Cost of running main engines, fuel oil/hr.	1·92	1·92	4·35	3·40
Cost of running main engines, lub. oil/hr.	0·132	0·132	0·02	0·02
Total cost of running main engines/hr.	2·052	2·052	4·37	3·42
Cost of running auxiliaries/hr.	0·113	0·274	included above	included above
Total cost of running main engines and aux./hr... ..	2·165	2·326	4·37	3·42
Cost of engineering personnel/hr.	0·21	0·21	0·24	0·33
Total cost of running main machinery incl. personnel/hr.	2·375	2·536	4·61	3·75
Ditto per nautical mile ..	0·223	0·238	0·450	0·365
Length of voyage per 100 tons fuel, nautical miles	1,960	1,784	770	512
Length of voyage per 100 tons fuel, hours	184	168	75	50
Cost of running propelling machinery, including personnel per 1000 tons nautical miles based on cargo deadweight..	5·50d.	5·91d.	11·6d.	9·95d.

Note.—The above is based on sea service, cargo heating is not allowed for, nor is there any allowance for fuel in port.

Price of Diesel Oil per ton, taken as	£3	15	0
„ Boiler Oil per ton	£3	5	0
„ Coal per ton	£1	14	0
„ Lubricating oil per ton	£25	0	0

It may be mentioned that Lloyd's give a list of more than 1000 tankers in commission with a gross tonnage of about 5,000,000 and 140 sailing vessels with 145,000 tons; and there are at the present time thirty-five steam and motor ships over 1000 tons under construction throughout the world for the carriage of oil in bulk. Thirty-eight and half per cent. of the total tonnage now building of all classes is to be fitted with internal combustion engines.

In reference to danger in carrying oil and spirit cargoes the risk of explosion or fire is generally greatest when vessel is empty and an accumulation of gas is liable to occur. An instance of fire at sea may be given which it will be noted originated in the pump room, and empty space.

On the *La Habre* carrying benzine, an explosion took place at sea in the pump room, and so damaged the bulkheads that spirit from the cargo tanks entered this space, and became ignited, boiled over on to the decks, set fire also to the liquid fuel in the bunkers, and in a short time the whole vessel amidships was enveloped in flames. Fortunately, as will be seen, a high sea was running at the time, and the vessel fell into the trough, and shipped a good deal of water, which washed all the burning spirit overboard, and away to leeward, leaving the vessel severely damaged, but with no burning spirit on board. She was able to make her way safely to port, having lost about 2000 tons of benzine.

Many tankers were torpedoed by German submarines during the war, and although severely damaged many were brought safely into port. In this connection it may be mentioned that during the war, at a time when the supply of fuel oil was of vital importance and the German submarines were paying particular attention to tank steamers, oil fuel was brought over by many ordinary cargo vessels in their double bottoms.

Considering the highly-inflammable nature of the cargoes carried in oil-tank steamships, the comparative freedom from loss and damage by fire and explosion, is a tribute to the skill and care exercised by those sailing in these vessels, and to the attention given to their construction. The extensive sub-division of these vessels renders them specially seaworthy.

Pipe-lines.

It will be realised that in many cases a considerable length of pipe-line is often required in order to connect tanks with vessel at discharging berth; it is, in places, imperative that these should be laid underground, but where possible, it is always advisable to keep all pipes above ground in a position easily seen. These pipelines consist of lengths screwed at both ends and connected by screwed sleeve sockets; the pipes being screwed hard up, it is advisable to avoid flanges as far as possible as in practice they are found more difficult to keep tight. There are several other forms of patent joints which are at times useful in confined spaces, but generally the screwed socket joint is to be preferred under ordinary conditions. The pipe-line at ship's end is connected to vessels discharging by flexible hose, either metallic or fabric, and if foundations of storage tanks are at all doubtful, it is advisable to connect them to pipe-lines with a metallic flexible hose, although in many cases copper or steel easy bends, or combinations of elbows are used. The tanks themselves are generally fitted with an internal swing pipe hinged in a packed socket, which can be raised or lowered to draw from any position in tank, this is useful at times

when oil has cleared first in the upper portion of tank, or when there is sediment at bottom. Moreover, when swing pipe is hauled up clear of surface of oil, no escape can take place due to an accident to line outside tank. A cap is fitted at end of swing pipe arranged so that oil flows over upper edge, in order to prevent suction disturbing sediment at bottom of tank when pipe is in a low position.

In certain places abroad, vessels are unable to come alongside and have to discharge from an open seaway.

In such positions pipelines have been laid on sea bottom with flexible hose, or specially designed hinged piping, which can be brought to the surface and connected to ship's discharge; in other cases discharge pipes have been laid on rafts connected by flexible hose or attached to floats in order to make connection with the shore. When it is necessary to cross rivers with pipe-lines it has been found advisable to reinforce each screwed joint with a heavy cast-iron sleeve made in halves and bolted together over joints. These not only strengthen joint but act as an anchorage to bed of river. In some cases it has been possible to joint pipeline on shore and float out and sink, or haul out into position; in others, pipes have been jointed on barge and lowered into water as lengths are added. The best means to be adopted are of course governed by conditions.

In laying sealines where depth of water does not allow of vessel coming alongside piers or jetties, similar methods must be employed according to position and facilities obtainable. Usually the tank vessel's pumps are able to discharge direct to tanks, but in some cases, when tanks are at a considerable distance from vessel, or are placed at a high elevation, it is necessary to instal high-pressure pumps ashore in close proximity to vessel which, after receiving oil from ship, transfer it to the distant or elevated storage.

It is of advantage to provide all pipe-lines of large diameter as this reduces the velocity of oil, and therefore facilitates the pumping by reducing the pressure necessary to force a certain quantity of oil through line in a given time. Where bends of large radius are impossible, expansion should be dealt with by packed joints. This is an important point, especially in tropical climates or when hot oil is being pumped.

In the case of liquid fuel, especially with Admiralty requirements, it is necessary to pass all oil delivered from vessel through filters before entering storage tanks, and this oil is again filtered before delivery to vessels. Filters should be of ample size in order not to restrict flow, wire gauze is generally used as the filtering medium, and care should be taken to avoid undue pressure being set up owing to insufficient area through mesh. Oil should

strike same diagonally, so that dirt is not held against gauze, and flow obstructed. Filters should be at least in duplicate, so that one can be cleaned whilst the other is at work, and thus avoid any stoppage of pumping. Under conditions of low temperature fuel oil is often unpumpable without heating, and for this reason storage tanks are fitted with steampipes carried in zigzag formation at bottom of tank, and pipe-lines from vessel to tanks, and *vice versa*, also require heating. This is done by carrying a steampipe through centre of pipe-line or by laying a steampipe close to oilpipe, and enclosing both in effective insulation. Means should also be provided for emptying pipe-lines, especially when of considerable length, after discharge of cargo from vessel, this is often accomplished with compressed air. Where spirit is received from vessels, steam is supplied from shore to actuate ship's pumps, no fires being allowed on board during the period of discharge.

Valves used on pipe-lines, and tanks should be the gate type, screw fitted, and index to show position of valve, and give, when open, a clear and unobstructed passage for oil.

Where the distances dealt with are comparatively small, the duplex direct-driven steam pump is mostly favoured on account of its giving a steady discharge, easy handling, flexibility and general reliability, but it is by no means economical in its consumption of steam. Power pumps, either electrically operated, or driven by internal combustion engines, are in some fields displacing the steam pump, but as steam is generally required for some purpose, the steam pump is likely to survive for some time. Without doubt, in many cases, sufficient care is not exercised in the design of pumps. Suctions should be as large as possible, all passages well rounded, and free from pockets, etc., likely to set up eddies. Valves and seats should have ample area, and without obstruction to the easy flow of oil as even a small obstruction in the valve seats, cross-guide bars for instance, considerably affects the efficiency. All stop-valves should be of the throughway gate type, with all edges rounded and bends avoided as far as possible, but if necessary a large radius. Although these requirements are important in all pumps, they are especially so in the case of large pipe-line pumps working under high pressure, and dealing with large outputs. The pumps up to the present are generally steam driven, either duplex, single compound, or triple expansion, and if water is available, surface condensing. For high pressures the plunger type of pump is sometimes preferred, but if the barrels and pistons are very carefully ground to a fit, the pistons being solid, of ample depth with circumferential grooves excellent results, and high efficiency can be obtained. The excessive friction with packing in large plungers is avoided, and there is also the advantage of being able to make the pump double acting.

Coefficient C, multiplied by velocity in ft. per sec.

Loss of Head per 100 ft. steel pipe with heavy Mexican oil of given viscosity.

Note.—For suction piping, the total loss including lift, if any, must not exceed 24 ft.

To find loss of head per 100 ft.:—
(1) Multiply velocity in ft. per sec. by coef. C.
(2) Read from base line to diameter.
(3) Horizontally read head.

Temp. F.	T	60	65	70	75	80	85	90	95	100	105	110	115	120
Coefficient	C	39·35	22·21	20·78	19·66	11·51	8·5	6·2	4·7	3·6	2·75	2·21	1·92	1·7

Velocity, feet per second.

Diam. in inches.	0·5	0·6	0·7	0·8	0·9	1	1·5	2	2·5	3	3·5	4	4·5	5	5·5	6	6·5	7
									Tons per hour.									
3	2·3	2·76	3·22	3·68	4·14	4·6	6·9	9·2	11·5	13·8	16·1	18·4	20·7	23	25·3	27·6	29·9	32·2
3½	3·13	3·75	4·38	5·0	5·63	6·26	9·39	12·5	15·6	18·8	21·9	25	28·2	31·3	34·4	37·5	40·7	43·8
4	4·08	4·9	5·72	6·53	7·35	8·17	12·25	16·34	20·4	24·5	28·6	32·7	36·7	40·9	45	49	53·1	57·2
5	6·38	7·66	8·93	10·2	11·5	12·76	19·14	25·5	31·9	38·3	44·7	51	57·4	63·8	70·2	76·6	83	89·3
6	9·19	11	12·86	14·7	16·5	18·38	27·6	36·8	46	55·2	64·4	73·6	82·8	92	101	110	119·5	128·4
7	12·5	15	17·5	20	22·5	25	37·5	50	62·5	75	87·5	100	112·5	125	137·5	150	162	175
8	16·35	19·6	22·9	26·1	29·4	32·7	49	65·4	81·8	98·1	114·5	131	147	163	180	196	212	229
9	20·7	24·8	29	33·1	37·2	41·4	62·1	82·8	103·5	124	145	165	186	207	228	248	269	290
10	25·5	30·6	35·7	40·8	45·9	51	76·5	102	127·5	153	179	204	230	255	281	306	332	357
11	30·9	37	43·2	49·4	55·6	61·8	92·7	123·6	154	185	216	247	278	310	340	370	402	432
12	36·7	44·1	51·4	58·8	66·1	73·5	110·2	147	184	220	257	294	330	367	404	441	478	514
13	43·1	51·7	60·4	69	77·6	86·3	129·4	173	216	259	302	345	388	431	475	518	561	604
14	50	60	70	80	90	100	150	200	250	300	350	400	450	500	550	600	650	700

The three or more throw-plunger pumps, however, give a very steady discharge. Air vessels of large capacity are indispensable together with air compressors to make up the loss of air by absorption and keep them fully charged.

In order to ascertain the probable loss of head through internal friction of pump and fittings, the following experiment was made. Water was the means employed, 99 tons per hour being pumped through a 10-inch line 93 miles (491,040 ft.). It was found that the theoretical pressure required to fulfil these conditions through a straight pipe, was exceeded by about 13 per cent. It may, therefore, be taken that this extra power was principally necessary to overcome the friction through valves, and fittings surrounding the pump. These figures point to the importance of ample margins when dealing with pumping problems; with heavy viscous oil the loss would have been greater. In connection with actual pumping data, experiments carried out by Messrs. Weir with Mexican oil are of great interest demonstrating clearly as set out in chart attached the influence of temperature, and viscosity on the flow of oil. Taking a 14-in. pipe with oil at a temperature of 60 deg. F., and a viscosity of 2450, velocity of flow 4 ft. per second, equals 400 tons per hour, it will be seen that the loss of head was 20·8 ft. per 100 ft. of length, but with oil at a temperature of 120° F. viscosity 120, the loss was only 0·9 ft. per 100 ft. Again, taking an 8-in. pipe, velocity 3 ft. per second—98 tons per hour at a temperature of 60° F., the loss of head was 46·4 ft. per 100 ft. length, but with temperature 120° F., the loss was only 2·2 ft. From this it will be realised what an important bearing the viscosity varying with the temperature has on the flow of oil, and, therefore, the power required in pumping. The advantage of employing a large pipe will also be noticed. This is, of course, what would be expected owing to the oil adhering to the internal walls of the tube, and thus restricting the effective area of cross section of pipe. With heavy viscous oil a comparatively small quantity of oil moves at the highest velocity, the actual velocity of the oil gradually diminishing from the centre to the circumference, where a film of oil adheres to pipe, and moves slowly, also, as the area of cross section of pipe varies as the square of the diameter, there is a greater proportion of oil moving at normal velocity, the larger the diameter of pipe. In an endeavour to overcome this difficulty the rifled pipe was introduced. This is rolled with large well-rounded corrugations, arranged longitudinally in spirals; the object being to impart a rotative motion to the oil passing through.

By introducing, with the oil, a small percentage of water, this being heavier, is thrown out to the internal circumference of pipe, and there forms a film of water acting as a lubricant to the

oil passing through, and preventing it from adhering to the walls. It is difficult to obtain reliable results, but the form of pipe does not appear to have made much headway, or to have been extensively adopted. It will be noticed that in the long-distance pumping data Weir's formula gives too great a loss of head. This is due to the oil being of a totally different class to the Mexican with which experiments were made. There are also many complications arising in long distances, such as gradients and variations of temperature, so that each particular pumping problem should be carefully studied, both theoretically and in connection with known results obtained by experience.

It may be of interest here to introduce some results obtained under ordinary working conditions.

PUMPING DATA.

Class of oil.	Temperature of discharge. deg.	Specific gravity.	Size of pipe-line. in.	Length of pipe-line. ft.	Pressure at pump lb. per sq. in.	Velocity of flow ft. per second.	Tons pumped per hr.	Remarks.
Mexican	110	·950	8	84,400	800-850	5·18	159	—
Burmah	85–90	·850	4	170,000	1125	2·7	21	During day.
„	80–85	·850	4	170,000	1200	1·33	11·8	During night.
„	100	·850	4	168,960	600	2·2	16·7	—
„	85	·850	8	10,050	150	3·2	98	—
„	85–90	·850	8	21,120	65	3·8	116	—
„	80	·850	8	20,000	80	3·6	112	—
„	82	·850	10	475,200	450	2·4	118	—
„	82	·850	10	723,360	400	1·5	74	—

Pump 10 in. × 30 in. Single double acting.
Steam Cylinders $\frac{16\frac{1}{2}\text{ in.} \times 25\text{ in.} \times 38\text{ in.}}{30\text{ in.}}$

ACTUAL PUMPING EXAMPLES (TANKERS).
MEXICAN OIL.

Class of oil.	Viscosity Redwood No. 1.	Temperature Fahr. of oil. Deg.	Specific gravity.	Size of shore line. in.	Length of line. ft.	Pressure per sq. in at pump.	Velocity of flow.	Tons pumped per hr.
Flux ..	40,000 at 100° F.	130	·980	8	2000	77	1·4	47·5
„ ..	40,000 at 100° F.	130	·980	8	2500	80	1·8	63
„ ..	40,000 at 100° F.	150	·980	10	200	25	6·7	356
Fuel ..	1500 at 100° F.	70	·852	8	2500	85	4·2	126
„ ..	400 at 60° F.	55	·908	14	400	40	4·6	448
„ ..	400 at 60° F.	100	·908	15	500	40	4·5	472

Generally, in long-distance pumping, a pressure of from 600 to 800 lbs. per square inch is carried at pump, but in some cases this is greatly exceeded, and intermediate stations are arranged some 75 to 100 miles apart, in many cases it is necessary to heat oil before a satisfactory output can be obtained.

It may be of interest here to mention some of the earlier transport of petroleum by pipe-lines.

The first successful pipe-line appears to be one laid in 1865. This was four miles in length and was laid underground from this date various lines were laid, one in 1875 of 4-in. pipe 60 miles in length was laid from lower oilfields to Pittsburg; from this date some fifteen different companies have been formed and are running lines throughout the States, one of the longest is that known as the New York line of 6-in. pipe from Oleun to Hunters Point, about 762 miles with eleven intermediate pumping stations.

In this case where it crosses the Hudson River, the oil-line is laid inside another tube which forms a jacket; it is held in place by two sets of heavy chain cables laid parallel with pipe and placed about 25 ft. each side, the line being connected to the cables at intervals.

In long pipe-lines flexible cylinders provided with spring scrapers usually known as "Go Devils" are often pumped through the lines with the oil in order to remove any deposit forming on the internal surface of pipe; at the end of a stage these drop into a box below, and clear of the line, from which they can be removed, cleaned and returned for another journey. In pipe-lines of considerable length, when exposed to the action of the sun, it is well to provide a relief valve fitted in a convenient position on the line, as it has been found that when the line has been left full, and the valves closed, the heating of the oil by the sun's rays has caused a very high pressure, owing to the expansion of the oil. Pipe-lines are in use in all parts of the world, and there are now in America alone some 45 to 50,000 miles of pipe-lines, which are constantly being added to, in addition to which great quantities of oil are transported by rail tank wagons, and by barges, or small craft on the waterways.

DISCUSSION.

Mr. G. W. E. Gibson thought the Congress owed a great debt of gratitude to the President of the Institution of Petroleum Technologists for having contributed in his paper so much of what he might call confidential information. Personally, he knew many marine consulting engineers, but he knew not one who would have imparted to the public practically a complete specification of a modern tank steamer.

The Chairman said he was sure every one present would congratulate the author on his excellent paper and the splendid slides with which it had been illustrated. He therefore asked the meeting to accord a hearty vote of thanks to Mr. Barringer for the trouble he had taken in compiling the paper, which should prove of much value and great interest.

The resolution of thanks was carried by acclamation.

Mr. Herbert Barringer briefly thanked the members for the manner in which the resolution had been passed.

Mr. F. G. Rappoport wrote subsequently:—I was interested in the pumping data given by Mr. Barringer in his paper on the Oil Tank Ship and in the remarks he made on long-distance oil pumping. I should like to add some remarks on this subject, particularly referring to the Maikop pipe-line running from the Maikop field to Ekaterinodar, of which I have some personal knowledge. As I did not have the exact data with me at the meeting, I regret that I was unable to contribute the information as part of the discussion at the time.

The Maikop pipe-line was constructed in 1910 in order to pump the oil produced on the Maikop field to the refinery at Ekaterinodar. The distance from the field terminal station at Khadijenskaya to Ekaterinodar is 282,170 ft.—*i.e.*, roughly 53 miles. The greatest elevation above the pump station is 234 ft. The line is 8 ins. diameter, and the pipes were designed for a working pressure of 1000 lb. per square inch, as pumping was to take place in one stage. Pumping power was supplied by three Worthington steam pumps capable of pumping 40 tons per hour each.

As bearing upon the remarks of the writer of the paper as to the effect of temperature upon pressure and quantities pumped, the following data in reference to the above pipe-line may be of interest:—

TABLE I.

When pumping high gravity oil sp. gr. 0·942.

Temp. ° F.	Tons pumped per hour.	Pressure.	H.P
86 ..	77 ..	1019 ..	200
68 ..	53 ..	1019 ..	150
50 ..	39 ..	1019 ..	115
32 ..	26 ..	1019 ..	85

TABLE II.

When pumping light gravity oil sp. gr. 0·88.

68 ..	112 ..	750 ..	—
50 ..	104 ..	945 ..	—
32 ..	96 ..	1000 ..	—

As the Maikop district is subject to fluctuating climatic temperature, I believe that the results obtained above led to the pipe-line, which was originally laid on the surface to be buried.

These data are further interesting in showing that the variations of quantity pumped with changing temperature are not so marked in the case of the oil of low viscosity as it is with that of high viscosity.

To which **Mr. Barringer** replied:—I am much interested in the information given by Mr. Rappoport in reference to pumping in the Maikop field, particulars of which I had not previously seen. As mentioned, it further shows the effect of temperature and viscosity on the amounts pumped at equal pressures.

The Chairman (Mr. Arthur W. Eastlake) said he much regretted to inform the meeting that Sir Frederick Black, who had been seriously ill for some weeks past, was unable to be present to read his paper. He had, however, sufficiently recovered from his illness to be able to correct a proof of his paper, which would be taken as read and was now open for discussion.

Bulk Distribution of Oil. Depots and Storage.

By Sir Frederick W. Black, K.C.B., B.A., Past-President of the Institution of Petroleum Technologists.

As the age of coal for marine purposes is passing away and the oil age is upon us, a review of the problems of oil storage and bunkering may fittingly begin with a slight retrospective sketch of similar problems of the coal age. It is, in fact, essential to present the *pros* and *cons* of coal in order to obtain a clearer view of the changes brought about by the newer fuel.

Coal has its problems of storage, handling and distribution, but obviously of a different character from those of oil. In temperate climates and in the ports of countries with ready access to coal mines, where in normal circumstances the replenishment of stocks is comparatively simple and expeditious, the provision of covered storage for coal is unusual; as the cost of such storage is likely to exceed the percentage of depreciation in the efficiency of the coal arising from exposure. The question is whether the customer would get the benefit in use of the added cost if storage were provided. Even in tropical climates, if turnover is rapid, and facility of replacement admits of stocks being kept relatively small in proportion to consumption, merchants who deal in coal for ships' bunkers are able to a large extent, and in fact as a rule, subject to special considerations, to avoid the expense of sheds. It is, of course, well known to engineers and others concerned that coal begins to lose some of its virtue from the time of its first exposure to the atmosphere. This loss is continuous, varying according to the nature of the coal, the duration of storage, climatic conditions, and the number and character of the handlings to which the fuel is subjected up to the point of reaching the furnaces. The storage of coal under water was advocated and experimented upon some years ago. The published results showed some advantage, but not sufficient apparently to justify the expense of

adopting this method of storage on a world-wide scale, under varying local circumstances.

Another variable factor affecting coal efficiency in use and the cost and methods of stoking, etc., is the proportion of "dust" and "small" in any particular delivery *ex* collier, wharf or lighter. It is not difficult to imagine a case, occurring in former days with ships of war rather than with merchant ships, of a large consignment in one collier being distributed to the bunkers of a number of vessels, alongside of which the collier would be placed in turn. The ships latest on turn in most cases received a much larger proportion of "dust" and "small," or "gravy" as the sailors sometimes facetiously called it, as compared with others. As a consequence, quantities consumed in relation to power produced, smoke emission, and the application of labour and skill of stoking, adjustment of firebars, etc., varied considerably in different ships of the same size, type of engines, and horse power; and the effort to maintain the same head of steam or speed was much greater in some of the ships than in others.

In regard to the relative merits of different descriptions of coal, much judgment and experience are brought to bear by coal owners, merchants and coal experts in determining the best markets for particular descriptions according not only to their calorific values, percentages of ash and volatiles, etc., but also in relation to their weathering or storage qualities under different conditions of climate. A brand of coal which, used fresh in a temperate climate, may possess superior steam-raising powers as compared with another brand consumed under the same conditions, may be more "friable" in hot climates, or make "small" and "dust" to a much greater extent under the same number of handlings.

Though consumers of coal may specify for "double screening," as compared with single colliery screening, a percentage of "small" and "dust" is necessarily occasioned by the "tipping" into colliers' holds, and by the action of grabs, picks, shovels, etc., in its extraction *ex* collier and in the subsequent handlings, till it reaches the stokehold. So strong is the engineers' natural feeling against excess of small coal and dust that the use of mechanical "grabs" was at one time regarded with anything but favour, as being liable to break up the coal; till experience showed that breakage from that cause was less than in shovelling, etc. The "grab" as a labour saving device, however, was mainly restricted to use on shore, and then only in special circumstances where such a method of working was economical.

One of the great benefits of our export coal trade to our national prosperity has always been the fact that sea transport outward and homeward was cheapened to the benefit of all concerned by running coal outwards and grain and other produce homewards.

Consequently, the general "tramp" steamer was available for coal carrying, and specially fitted colliers were provided only for exceptional services and requirements. It was not, therefore, an economical proposition to equip "tramp" steamers with coal "grabs," etc., as their use would ordinarily be limited to a few exceptional occasions.

In the world's great coaling ports, a considerable variety exists of methods of handling coal, whether by machinery, or buckets and baskets man-handled. Speaking generally, it will be found that where native labour is plentiful and efficient, there is little room for coal-handling machinery. The high averages per hour attained by local hand labour in the delivery of coal at such ports as Port Said, Singapore, Hong Kong, Nagasaki and elsewhere are well-known, utilising as a rule comparatively small hand baskets which are carried along planks to the bunkers, or occasionally passed from hand to hand to persons on stages slung to the ship's side. Occasionally, in the case of warships, the whole of this work had to be done by the crew, from the filling of baskets, sacks or tubs in colliers or lighters, to the inboard work of trucking to bunkers and trimming. The operation was laborious, grimy and anything but agreeable; yet officers and men threw themselves into the work with a will, and established records of fast coaling for particular ships. The nuisance of the penetration of coal dust to cabins, etc., in the operation of coaling is known to all who have experienced it. The smoke nuisance as a rule is not much to be complained of in passenger ships. The action of sulphur on ships' gear is not always negligible. In ships of war it is obviously important to minimise smoke emission, in order not to increase the visibility of the ship to an enemy.

When coal has reached the ships' bunkers it has yet to undergo many laborious operations of shovelling, trucking, stoking, etc., before its final consumption in the furnaces. Welsh coal, which on its merits holds the highest place in the markets for its steam-raising value, is slightly more difficult in handling, owing to large lumps, than coal such as the American Pocohontas, Japanese and other descriptions. The smaller coal, however, requires special stoking and adjustment of firebars.

Consideration has been given to the possible use of "pulverised coal"—*i.e.*, coal specially crushed to a fine powder for marine purposes. Such coal is largely used for cement making and in various large plants in America, and to some extent in England and on the Continent. It has been tested also, here and in America, for locomotives. For marine purposes, however, the storage and the handling into and out of bunkers, of a powdered fuel, highly volatile when mixed with air, and greatly absorbent of moisture, present many difficulties. Mr. James Richardson, in

his article on "Marine Engineering To-day" (p. 259 of *Brassey's Naval and Shipping Annual*, 1924), points out that the danger and difficulties of handling pulverised coal can be largely overcome by carrying out the pulverising on board ship, by means of comparatively small units of plant, no more costly than chain stokers. He remarks, however, that "much more development ashore" will be necessary before such devices are likely to be adopted on board ship. We may add to that remark that, should such a development occur—*e.g.*, in the case of a temporary shortage of oil—all the disadvantages of handling lump coal and the upkeep of bunkers, etc., will remain, up to the point of reaching the pulveriser. From that point onwards, however, there is the saving of stoking, etc., to be set off against the operations of crushing and pulverising. The dust is sprayed into the furnace through a "burner" in the same way and into the same type of furnace as oil. Therefore, it is possible to change readily from the one fuel to the other—*i.e.*, from pulverised coal to oil, or *vice versa*—without modification of furnace grates, etc. Moreover, it is claimed for the pulverised coal that, given uniformity of feed, the efficiency is far higher than with lump coal, owing to the enormously increased exposure to the air of the innumerable fine particles in the furnaces, as compared with air action on lumps of coal. As Dr. Diesel's original expectation of the use of pulverised coal in his type of internal-combustion engine has not yet materialised, the interchangeability of oil and pulverised coal is limited to burning under boilers and is not practicable in ships employing the Diesel types of engines.

No amount of "pulverising" of coal by itself—*i.e.*, unaccompanied by cleansing methods, not as yet, if at all, to be regarded as feasible on board ship—will eliminate ash, etc., which in some way must be got rid of. Any extensive development that may take place in the use for marine purposes of pulverised coal seems more likely to be in combination with a proportion of oil, either by mixing on shore or in a special tank on board prior to spraying, or by combining the two in the burner at the moment of spraying into the furnace. One of the problems here involved is the production of an homogeneous fuel—*i.e.*, of a fairly uniform combination of the oil and coal at the moment of combustion. There are various devices, *e.g.*, for agitation of, or other action on, the mixture in ships' tanks to prevent settling out of the coal, or for combining the coal dust and oil in, or on emission from, the burner. Here, again, much more development on shore will be needed before this fuel finds its way to extensive use afloat. It is obvious, however, that should such a mixture prove successful afloat, as it has done to a limited extent on land, the use of a proportion of coal dust, up to possibly 50 per cent., might prove in certain circumstances an extremely valuable supplement to fuel oil, in event of any tem-

porary oil scarcity. The same or similar burners and furnaces as for oil fuel alone are used for the mixture. Ash elimination and one or two other practical points have yet to be completely surmounted. As in the case of pulverised coal used by itself, it has to be remarked that the use of pulverised coal in combination with oil has not yet proved successful in engines of the Diesel type.

The use of coal in the gaseous form, which has developed so extensively on land, does not appear to be a probability of the near future afloat. Much experiment has been and is being made, both commercially and by the Government Fuel Research Committee under Sir George Beilby, in regard to the extraction of oil from coal by low-temperature distillation, etc. Unquestionably, in time of any restriction of the production or import of natural petroleum oil, such developments will be of great importance and will be greatly stimulated. At present the main difficulties appear to lie in the adaptation of different retorting and other operations to many varying grades of coal, the cost of the various processes involved, and also in the finding of commercial markets for all the products obtained.

It will be evident from the foregoing that coal as a ship's fuel possesses considerable drawbacks of handling, etc. Its value in use is subject to a rough practical "differential," hardly, if at all, expressible in money, according to its age from time of mining, length and conditions of storage, number of handlings, etc., and time and expense occupied and incurred in handlings after the coal has been brought alongside.

Having grumbled somewhat at coal because it is black and grimy and laborious to manipulate, whilst oil is moved mechanically and more or less unobtrusively in pipes, etc., let us now turn to what our coal resources have done and are doing for us as a nation or as an empire, outside of domestic and internal uses. Brief allusion has been made already to the advantage of coal to us as a carrying, exporting and importing people. Not only our shipowners, shipbuilders and seafaring folk benefit, but consumers of food and of all imported products and materials; in fact, our whole population in some way or other. The advantages of supplying coal to countries overseas for railway purposes, industrial plants, gas works, and domestic services, as well as to our own numerous bunkering stations abroad and at many neutral ports, are obvious in the promotion of world-wide trade and commerce. Our position as a seafaring nation, with communications to maintain with our kinsmen in the dominions overseas, as well as foreign nations with whom we have relations, has been enormously strengthened by this valuable resource.

The national and imperial importance of our British coal supply and that of many dominions within the Empire, *e.g.*, Canada,

Australia, New Zealand, India, and South Africa cannot be exaggerated. We may repeat here what many others have already said, viz., that in no circumstances at present foreseeable can oil completely supplant coal. The world's annual oil production in 1923, say, 138,000,000 tons (nearly) is only about 11 per cent. of the world's annual coal output, say, 1,200,000,000 tons. Taking into account very approximately the various and relative uses and efficiencies of coal and oil respectively, *e.g.*, if one ton of oil be taken as equal all round to something like two tons of coal, the percentage of annual oil to coal production on the basis of quantity plus efficiency would still not exceed some 22 per cent. The underground resources of coal are also generally estimated as exceeding many times the world's potential supplies of natural petroleum. Let it be remembered also that much of the work done by the lighter of the oil fractions, viz., gasoline (or petrol) and kerosene (to some extent) in internal-combustion engines, *e.g.*, in air craft and all motor vehicles and light swift vessels, could either not be done at all with a product of coal or generally speaking only at a higher range of cost or reduced efficiency. Taking their fields of use as a whole, therefore, coal and oil will continue to be complementary and supplementary to one another.

We may now proceed to consider oil from the storage and distribution point of view. In the case of oil, bulk storage is of importance the moment the crude oil issues from the well. Obviously, special storage of a "liquid" is compulsory, whilst that of lumps of dry material is voluntary. So valuable a product as oil cannot be allowed to dissipate itself and run to waste. Where the flow of the wells is moderate or pumping is resorted to, also upon large fields, with a number of wells in bearing and employing the best methods for capping or regulating the flow of particular wells, the provision of adequate storage tanks in proportion to production is mainly a question of prudent management and finance. Where the field is new and isolated, or where large gushers come in unexpectedly, the provision of temporary storage in available vats, etc., or puddled reservoirs, or by means of the hasty laying of pipe-lines to the nearest "farms" of steel tanks, or to the storage at the refineries, becomes a matter of urgency, in order to keep the percentage of loss down to as low a figure as possible. In earlier days, before the volatile fraction now known as motor spirit or gasoline had acquired the higher value which the invention of the internal-combustion engine has given to it, some evaporation or "topping," by the sun's rays, of crude oil, whilst lying in open or imperfectly covered reservoirs, was regarded more or less with equanimity. The residual oil, *i.e.*, after the sun had taken its toll and thereby brought about a higher and safer flash point of the bulk that was left, was sometimes used without under-

going any artificial refining, under boilers on land or in river and coasting craft, according to local circumstances and the description of the oil. A perfect adjustment of supply to a demand, by accessible markets at remunerative prices, for each and all of the products capable of being refined from a particular quality of crude oil, is an ideal never actually attained. Yet, in a practical and progressive way, there is a much closer approximation to that ideal than was formerly the case. In earlier days of the oil industry, large supplies coming in unexpectedly had often to be disposed of for whatever purposes they could be most readily used; until the development of additional or more complete refining capacity and of transport, working hand in hand, enabled the world's requirements of petroleum products to be met in a more advantageous manner. The world's demand to-day comprises refined and manufactured products for a great variety of uses, *e.g.*, motor spirit of varying grades, kerosene or lighting oils, lubricants, heavy residual oils, suitable according to grade either for use under boilers, or for engines of the Diesel type, wax for candles, pitch, asphalt, carbon or coke, etc. It is, of course, well known that not every crude oil will yield the same constituent fractions or the same proportions of each. A further and detailed consideration of these matters, however, appertains to the economical refining of various types of crude according to the commercial demands for particular products, rather than to storage and distribution. It may be mentioned, however, that, broadly speaking, crude oils fall into three main classes, *e.g.* (1) those of an asphaltic base, (2) those of a paraffin base, and (3) those of a combined asphaltic and paraffin base. Classes (2) and (3) will contain some proportion of wax. The percentages of the lighter fractions, *e.g.*, of motor spirit and lighting oils, will vary greatly from one type of crude to another.

We have seen in the case of coal that covered storage is provided only in special cases. In the case of oil, closed-in tanks, constructed almost invariably of steel, are used:—

(1) At or near the oil wells, for crude oil, etc.

(2) At or near the refineries for crude oil and all liquid products.

(3) At bunkering ports or inland distribution bases, and at places of actual consumption.

It may seem at first sight that oil, as compared with coal, suffers some handicap of cost owing to this necessity of covered storage. On the other side of the account, however, must be set a number of very important considerations. Oil products kept in steel tanks of proper construction suffer very little, if any, deterioration. Some slight evaporative loss may have to be faced in hot climates,

especially in the case of the lighter products. In the case of the heavy residuals, some deposit of solid matter may occur in time; and also certain oils show a tendency to become more viscous and may require the application of steam heat in steel coils to promote fluidity and facility of pumping. Speaking generally, therefore, it follows that in the case of oil a practically uniform standard of quality can be maintained with little or no deterioration from the standard of original efficiency, even after years of storage. Consequently, it is practicable to hold larger reserves against variations in consumption.

The method of transport of oil in bulk by means of pipes and pumps on a large scale is far more efficient and normally more economical than bulk handlings of coal, and is an infinitely less laborious operation. These advantages, resulting in saving of time and cost, are important both to merchant shipping and to ships of war. In the case of the latter more particularly there is the added advantage that oil can be transferred from tank vessels at sea whilst the fleet is on passage, the warship towing the tanker or *vice versa* according to relative size, etc.; whilst the hawser is taut, the flexible steel hose is "bighted" to avoid strain, and oil can be pumped over in all ordinary weather.

In the case of coal, practically no stocks are held at pit's mouth, except such as can be accommodated in railway trucks on the limited sidings available; consequently, the moment a cessation occurs in the taking away of coal to the docks for shipment, or to consuming centres generally, the colliery ceases working. A few days' rough weather may delay the arrival of colliers expected at certain dates at loading ports; the working of coal at the pits is then suspended and prices begin to fluctuate at once. On the other hand, as we have seen, in the case of oil there are three sets of stocks that stand between the consumer and any such stoppage of production. It has to be admitted that coal production as compared with oil has the advantage of more rapid and complete adjustment of supply to demand from the power of immediately ceasing to hew or win the coal when demand or facility of removal decreases, and from the fact that only a "raw" material is handled by the producer.

Yet the advantages of the larger above-ground reserves of oil are very considerable from the consumers' point of view. There has been a tendency in the last few years, particularly in the oil trade of America, to increase the margin of available tank storage at each of the three points named above, with a view to exercising a steadying influence on market prices, *i.e.*, on the one hand to check to some extent the increases which the consumer naturally views with so little favour, and on the other hand the sudden depressions which are unremunerative to the producer. There comes a point,

however, at which the cost of tanks and the locking-up of capital in reserve stocks become prohibitive. A reserve of storage capacity can only be regarded therefore as a partial and minor safeguard against market fluctuations.

As it is not contemplated to deal herein with oil tanks, pipe lines, pumps and other apparatus from the technical standpoint, it is only necessary to remark very briefly on the general type of tank storage that has established itself for oil storage and distribution, and to emphasise the general advantages of the supply of fuel by pipe line and pump, ashore and afloat.

Much experiment has been made in the United States of America in regard to the possibilities of concrete tanks for oil storage. In very favourable circumstances some measure of success in the use of concrete for oil tanks has been obtained, *e.g.*, in countries where there is comparative freedom from those climatic and other influences which may produce expansion or contraction of material such as concrete. Even so, great care is necessary in construction and in the selection and incorporation of materials. Against this must be set a number of failures. If concrete tanks should establish themselves as safe and economic storage for oil in effective rivalry with steel, which does not seem a probable contingency at present, it may be expected that their use would be restricted to the heavier types of fuel which would be less penetrative in their effect than motor spirit and lighter oils. Experiments on a small scale have been made in the storage of motor spirit in very specially constructed concrete tanks, but although a certain measure of practical success was achieved, the experiments on the whole confirmed the superiority of steel tanks both on practical and economic grounds. As an incidental illustration of the almost universal use of steel tanks for oil storage it may be mentioned that at the port of Tampico (Mexico) out of a total of about 1870 tanks, 1839 tanks are made of steel.

Concrete tanks, if proved to be oil-tight and economical in cost, would have some advantage from the point of view of Naval and Military strategy, as lending themselves rather better to concealment of their presence, as they admit of being placed at least partly underground and of being covered with earth, etc.

The size of oil tanks varies widely, according to the description of product, turn-over, etc.

The general run of fuel oil bunkering tanks at depots of importance is from 2000 tons to 10,000 tons. A very usual type of steel tank for large storage was for a long time, and to a large extent still is, the 55,000-barrel tank (*i.e.*, between 7000 and 8000 tons). There are probably a few instances in which the limit of 10,000 tons is exceeded for special circumstances. The limitations of tank capacity are economical and practical rather

than technical and mechanical, as is the case also with oil tank steamers. At depots that are situated at a considerable distance from the sources of oil supply, the size of the shore tanks will be governed to some extent not only by the extent of the prudent reserve necessarily held against a given turnover, but also by the necessity of providing a margin of capacity to receive as a replenishment the minimum quantity that can be economically and conveniently delivered by the sea-going tanker, having regard to her trim and whether tanks at some neighbouring port are being replenished on the same voyage.

The superiority of oil over coal in its power-producing efficiency has been stated on many occasions. The latest issue of *Brassey* (p. 614) gives the relative efficiencies of coal and oil under boilers, and of oil for Diesel types of engines as follows, for a ship of about 10,000 tons dead weight and average horse-power about 2500 to 2800 :—

	Diesel engines (4 cycle).	Reciprocating steam engines, triple expansion, etc.		Turbines with reduction gearing, etc.
	Oil.	Coal.	Oil.	Oil.
Fuel consumption per day, in tons ..	12·1	53·3	37·5	29·5
Do. per voyage of 16 days in tons ..	194	856	600	472
Cost of fuel per 16 day sailing : Oil for Diesels, £4 a ton ; Oil for furnaces, £3 a ton ; Coal at 25s. a ton ..	£776	£1070	£1800	£1416
Cost of running for one year of 288 days sailing	£20,628	£27,096	£39,168	£32,265
Freight earning cargo, in tons	9357	7880	8555	8743

It is stated that in the case of the Diesel ships the above figures do not take account of less fuelling costs, less demurrage, less cleaning of ship, higher average speed at sea, reduced fuelling appliances, etc., nor of the fact that oil at cost as shown for boilered ships may sometimes be usable for Diesel engines.

Obviously figures such as the foregoing will vary somewhat with changes in prices of coal and oil respectively, but except in the cases of abnormal circumstances restricting or suddenly increasing the available supplies or cost of production of the one fuel or the other, the costs of coal and oil, though varying from time to time, are likely to bear a fairly uniform relation to one another.

It may be pointed out at this stage that whilst in the long run the use of oil will increase the cargo-carrying capacity of a vessel, by the fact that greater power per ton weight of oil is obtained than from a ton of coal, and by the use of ballast tanks, etc., for oil storage, the full advantage of the extra weight-carrying power

may not be always obtainable, *e.g.*, if the freights in one direction, especially starting from a cheap coal port, are scanty compared with those obtainable on the voyage in the reverse direction. In such cases coal is still frequently used in the one direction and oil in the other, the use of the coal, however, being subject to some disadvantage in carrying extra trimmers and stokers for either the round voyage or at any rate for part.

Upon the basis of such comparative results as those stated above, eminent naval and oil experts frequently call attention to the "sin" of burning heavy fuel oil for steam raising, instead of reserving it for Diesel types of engines. Whilst it is of great service to the cause of economical use and conservation of fuel that this important point should be stated and re-stated with all the emphasis that high authority can command, it must not be supposed that this counsel of perfection is immediately to be realised in present circumstances. Nevertheless, it may be recorded that immense and encouraging progress in the more economical use of oil for marine purposes has been made in recent years, and some of the best brains of this country and others have been and still are engaged on the problem of further improvements.

First of all let it be remembered that a large proportion of the world's supply of heavy residual oil is not suitable for existing types of Diesel engines, mainly on account of the high percentage of "asphalt." Such fuel may, however, be excellent for steam raising. The heavy residual fuel has been produced in the obtaining of other products, *e.g.*, motor spirit and lighting oils required by the world's markets. Consequently, the residual fuel must also find its best market. It follows, therefore, that its use for steam-raising ashore or afloat in certain circumstances may be quite justifiable and necessary. This condition, however, may be modified if, on the one hand, the refiner can profitably "cut out" a percentage of asphalt; or, on the other hand, if the designer of the Diesel engine can see his way, without impairing the efficiency of his design, to modify his engine to use the fuel with the higher "asphaltic" content.

It is well known that the Diesel type of engine presents a great advantage of economical fuel consumption. The above table shows a comparative consumption (approximately) of 1 ton of oil in the Diesel ship to 4½ tons of coal, and 3 tons of oil in steam ships with reciprocating engines, and 2½ tons of oil in ships with geared steam turbines. From the highly desirable point of view of economy of fuel consumption and conservation of the world's resources of fuel, it would be desirable that all marine propulsion should be on the Diesel basis.

Does it appear practicable or probable, however, that the Diesel engine will supersede all other types, including the geared steam

turbine, for ship propulsion? It cannot be said that this is probable. The Diesel engine has made great progress in the last few years, not only in the number and size of ships so propelled, but also in the improvements in the engines themselves. Ships up to about 20,000 dead weight are built or are building for Diesel engines. Mr. J. Richardson (in the article above quoted, p. 270 of *Brassey*) mentions as an illustration of the revolutionary development of power, the case of the machinery of a Swedish-American liner under construction in which 13,500 h.p. will be developed on two shalts by six cylinders per shaft. "Each cylinder of 31½ ins. diameter develops 1125 B.H.P."

In regard to tonnage of motor ships and of oil-burning ships generally, *Lloyd's Register* shows the extent of the development. Less than 69 per cent. of merchant shipping depend on coal alone, 24 per cent. use oil for boilers, and nearly 3 per cent. are motor ships. The world's total of motor vessels exceeds 800, and the tonnage is about 1,300,000 tons. The British Empire owns about half the total number and about one-third of the total tonnage of motor vessels. A fifth of the total number and about a third of the total tonnage are owned by Norway, Sweden and Denmark. The importance of utilising the most economical fuel consuming vessels, apart from the general obligations of fuel conservation, is naturally more strongly felt where the resources of oil which any particular maritime country may own or control are limited.

Some three years ago it was announced in a British Government despatch and in Parliament that the British Navy had become over 90 per cent. oil fired, as compared with 45 per cent. before the war. The other principal navies of the world are also large oil consumers; the advantages for naval purposes being such as to render oil an essential fuel, which no nation can afford to forego, whatever its oil resources may be. Whilst Diesel or other internal-combustion engines are used in a few types of war vessels as the main propelling engines, their use for naval purposes appears to be limited very largely to auxiliary purposes only, owing to consideration of weight, disposition of weight, spare parts, etc. The hope that was and is still entertained that the advantages of the turbine may yet be combined with the low fuel consumption of the Diesel awaits fulfilment till metallurgical and other difficulties can be overcome. For some considerable period, therefore, the burning of oil under boilers is likely to continue, for the two reasons indicated, viz., that not every description of heavy fuel is suitable for Diesels, and that the Diesel is not likely to be able to "take care" of the whole of the world's marine propulsion. Whilst, as stated, the Diesel type of engine is improving, and its use is being largely extended, there is still much discussion and consideration necessarily given by shipowners and others to important points

such as (1) comparative first cost of Diesel and steam engines respectively, (2) relative cost of upkeep, (3) replacements of spare parts in Diesel engines involving problems as to what parts shall be carried on board and how far engineering establishments at ports abroad are stocked and equipped for this work, (4) at what ports and at what cost are oil supplies obtainable of a quality suitable for Diesel engines, and (5) to what extent must subsidiary engines be provided for working of winches, etc., or in tank steamers to supply steam for cleansing of tanks when a class of oil differing from the previous cargo has to be carried.

In ships of war probably the question of aggregate weight and its disposition is regarded as of special importance. If the horse-power per cylinder may be taken as likely for the present to approximate to 1000 h.p., it is apparent even to the mind of a non-expert, that the provision of 60 or 70 cylinders needed to produce the horse-power of some of our largest "liners," or the 140 to 150 cylinders, to obtain the power of a first-class battle cruiser, involves very special problems of weight, possible damages, replacements of parts, etc. Consequently, ship and engine designers and builders, with every desire to economise in fuel consumption, have to weigh in the scale with such economy, many factors of the highest importance in regard to efficiency and cost, in determining the best type of propelling machinery to be adopted in any given vessel according to her potential service and efficiency.

The whole of the foregoing remarks had been written before the important speech of the Engineer-in-Chief of the Navy, Vice-Admiral Sir Robert B. Dixon, K.C.B., was delivered at the dinner of the Institution of Petroleum Technologists (March 18). The Engineer-in-Chief, in the comparison which he made between Naval and Mercantile marine engine problems, drew special attention not only to the considerations of weight, space, etc., but also to the high horse-power necessary to obtain a speed in cruisers and destroyers far in excess of what is required in the fastest of the great ocean liners. His remarks further emphasised what is already generally known, that the British Admiralty keeps abreast of engineering developments and improvements, adaptable to the exceptional requirements of vessels that must possess the highest efficiency for war service.

Before dealing particularly with the consideration raised at (4) above, viz., the present state of supplies and distribution of oil of various grades for marine engines, a brief remark or two may be made on the subject of tank steamers. The advantages and disadvantages in the case of coal arising from the employment of general utility or "tramp" cargo vessels for its transport have been touched upon already. Tank steamers are specialities, built as a rule for the one purpose of carrying various grades of petroleum

oil in tanks in bulk. The fact that oil tanks afloat and ashore are filled through pipes by gravity or pumping, and emptied similarly, makes for efficiency and saving of time as compared with either loading or unloading coal or other miscellaneous bulk cargoes. The tankers usually employ oil as their fuel under boilers or otherwise, which tends to economy of working expenses. They can discharge in stream to lighters or to ships' bunkers. In loading and unloading at shore depots the tank vessel can be reached by flexible steel hoses. Accordingly the expense of jetties, dolphins or other berthing accommodation at oil depots is usually much more economical than the dock quays, wharves, etc., used by ordinary cargo vessels. All of these conditions help to reduce detention or demurrage charges. The disadvantage of not being adapted or readily convertible to the carriage of ordinary merchandise on return or intermediate voyages is largely or wholly outweighed by the advantages above referred to. In actual fact tank steamers in various parts of the world are frequently employed to carry oil cargoes of one description (*e.g.*, crude) in one direction, and in distribution of manufactured products, residuals, etc., to various ports on the return voyage. The number of "ballast" voyages is thus considerably reduced.

The great progress that has been made in the provision of oil tanks at the world's bunkering ports may be gauged from an examination of the lists published in some of the oil and shipping journals, etc. In such lists a few particulars are occasionally given in regard to the tank storage capacity at various ports and also where special qualities of oil for Diesel engines are kept. These, however, are matters in regard to which shipowners are able to inform themselves by inquiry beforehand for particular voyages, and prior arrangements are usually made to insure that the necessary supplies shall be available. Oil burning ships as a rule need fewer points of supply than coal burners. Fuel oil supplies are now stocked world-wide, although the question of available quantities and qualities at particular times and places may still require previous ascertainment to a greater extent than in the case of coal supplies, in order to prevent delay, inconvenience and disappointment.

The world's coal bunkering ports are so numerous and widespread that it is unnecessary to either specify the total number or even a few of their names. For commercial oil bunkering ports a rough approximation to the total number (excluding a number of small depots) is given below. The variations, from one year to another, and from one port or coast to another, of requirements of coal or oil fuel for bunkers, are of course very considerable, depending on the extent of cargo carrying and the direction in which cargoes are moving.

The total of about 64,000,000 tons of coal shipped as overseas cargoes from British ports is utilised in the importing countries for bunkers, railways, industrial plants, gas works, etc.

The world's consumption of coal for bunkers for the year 1922 may be taken at about 32,000,000 tons, of which rather more than 18,000,000 tons were supplied at ports in the United Kingdom (this figure is additional to that of the coal shipped as "cargoes") and about 6,000,000 tons at ports of British Dominions overseas, *e.g.*, South Africa about 1,300,000, India 1,900,000, Australia and New Zealand 1,600,000 tons. In the case of the principal British overseas dominions the bunker supplies are mainly from coal mined locally. Many coaling ports in Europe and on the main ocean routes are supplied with coal from either the U.K., or, in the East, from other British sources of supply. The balance of the world's coal bunkering total is principally made up of supplies of about 4,250,000 at ports of the U.S.A. of America and 2,250,000 tons at Japanese ports and of British, American, Japanese and other coal at ports of countries that have no coal production of their own. Both U.S.A. and Japan have a considerable export of coal in cargoes for general industrial purposes, including bunkers. The world's present-day coal production and distribution (including coal for bunkers) do not in the aggregate exhibit any very material difference from the figures of years immediately before the war; *e.g.*, the U.K. then exported about the same total of 64,000,000 tons as cargo, and shipped at U.K. ports about 18,000,000 tons for overseas bunkers.

There are to-day upwards of 300 oil bunkering stations (excluding those of minor importance) in various ports of the world. There is hardly a port of any standing which does not possess oil supply facilities in addition to those for coal. There are some 25 ports in the U.K. with oil bunkering equipment and about 40 in other ports of the British Empire. Great Britain also owns or has an interest in a number of oil installations elsewhere. Other Northern and Western European countries possess about 40; there are about 30 in the Mediterranean and Black Seas; America, Canada, Mexico, West Indies, etc., account for some 80 or 90; and the remainder are to be found in the Red Sea, Persian Gulf, India, Dutch East Indies, Malay Peninsula, China, Japan, Australia, South Africa, South America, etc. At many ports may be found three or four separately owned oil installations. The capacity of the world's commercial oil tank storage at sea and river ports (excluding Government tanks, and as far as separable tank farms on oil fields and at refineries, also inland distributing stations) is probably not much less than 20,000,000 tons, of which Europe accounts for nearly 3,000,000 tons, U.S.A., Canada, Mexico, etc., probably some 15,000,000 tons, and the balance is distributed over Asiatic,

Australian, African ports, etc. Of the world's total production of crude oil, it may be estimated very approximately that the consumption of heavy fuel absorbs about two-thirds, including the quantities used at oil fields and refineries, also solid products (pitch, asphalt, wax, etc.) as well as evaporative losses, etc. About one-third of the world's crude is utilised in the form of motor spirit, lighting and lubricating oils. The largest consumers of heavy fuel oil are railways and industrial plants in the United States of America. The world's consumption of fuel oil for ships' bunkers (mercantile) may be taken very approximately at about 9,000,000 tons in 1920, and about 11,000,000 tons in 1923, excluding the fuel oil consumption of the world's navies or war fleets. The oil bunker supplies of 1923 were effected approximately as follows :— At ports of the United States, Canada, Mexico, West Indies, etc., about 6,500,000 tons ; at United Kingdom ports (imported oil) about 1,000,000 tons ; at other European ports, Africa, India, Australia, Dutch East Indies, Malay Peninsula, Japan, etc., about 1,500,000 tons. In the United States of America the large home production of oil was equal in 1923 to nearly 75 per cent. of the world's total. The U.S.A., moreover, has a large import of Mexican crude and heavy fuel oil, which enables the higher grades of American crude oil to be refined as far as practicable to produce the maximum of motor spirit, lighting oils, etc. American lighting and lubricating oils find their way to most of the world's markets, and America is also a large exporter of motor spirit. The American domestic consumption of motor spirit, however, has reached a figure which suggests that her export of that product to other countries may have to be curtailed in the near future, unless again home production of crude oil continues to increase at a rate that will both meet her own growing requirements and also yield an exportable surplus. The American crude production of 1923 exceeded that of the previous year by about 30 per cent. In regard to motor spirit, America with about 15,000,000 motor vehicles, is always in a favourable position in times of stringency or emergency to curtail its use in motor cars, etc., in favour of other essential services, such as air craft or motor transport in war time, etc. Other countries with a much smaller number of vehicles and dependent on imported oil are less favourably placed in this respect ; though in so far as supplies are available, obviously the same policy can be pursued as was done in the late war. The United Kingdom has about 650,000 motor vehicles exclusive of motor cycles, and consumes 1,200,000 tons of motor spirit, mostly imported. If it should eventually prove that the U.S.A. export of motor spirit may have to be restricted, the effect would be to stimulate the production of larger quantities of motor spirit from other oil fields, both by the earlier development of new fields, and

possibly by the extraction of large proportions of motor spirit from a given volume of crude oil at the expense of some of the heavier fractions. It may be expected also that encouragement would be given to the increased production of benzol (a coal product) and possibly of "power alcohol," a vegetable product. Civilisation usually has a spare shot or two in its locker, although not to be made available except by previous preparation, forethought and care and possibly not without temporary inconvenience.

The following table gives the world's recent production and consumption of petroleum (years 1921–22–23).

	1921.		1922.		1923.	
	Tons.	%	Tons.	%	Tons.	%
Motor spirit or gasoline ..	16,629,000	16	20,031,000	17	24,788,000	18
Kerosene lighting oil	8,552,000	8	10,016,000	8·5	13,082,000	9·5
Lubricating oils..	4,146,000	4	4,713,000	4	5,508,000	4
Fuel and gas oils	63,861,000	61	72,466,000	61·5	85,379.571	62
Balance used on fields, at refineries, etc., also in the form of wax, pitch, asphalt, etc.	12,018,000	11	10,605,000	9	8,951,084	6·5
Production of crude ..	105,206,000	100	117,831,000	100	137,709,000	100

It will be noted that the world's consumption of heavy fuel for marine bunkerings is still a comparatively small proportion of the total production of heavy fuel, thus admitting considerable interchangeability as between requirements ashore and afloat according to fluctuations of demand.

The world's crude oil production over the past forty or fifty years has usually rather more than doubled itself every ten years. That rate of increase in the last three years up to the end of 1923 has been more than maintained. The year 1923 showed exceptional production, yielding, as shown in the above table, a total of crude oil of nearly 138,000,000 tons, *i.e.*, upwards of 16 per cent. increase over (about 118,000,000 tons) of 1922. Some falling off in Mexico was more than made up in California and Texas, whilst Persia and the Asiatic fields generally showed an increase. California and Texas at the moment have declined somewhat, and it would seem probable that the recent percentage of yearly increase is hardly likely to be maintained. Still, it is always well to make the customary remark that wonderful things often happen in oil production.

The quantities of oil held in storage necessarily fluctuate with the temporary increase or decrease of demand and supply. It is not necessary here to enter in detail upon the question of the probable adequacy or otherwise of the world's oil supplies, or their

prospective duration. On the best evidence of oil geologists and practical oil experts, the world's oil supply of natural petroleum from wells or oil extracted from shale, coal, etc., will probably meet requirements for several generations. The consumption of heavy fuel for marine purposes may be expected to be more and more on the Diesel engine basis, as stated above. This will, of course, lead to economy of fuel in the aggregate, but it has to be borne in mind that Diesel-engined ships are dependent solely upon oil as their fuel. They cannot convert to coal as ships burning fuel under boilers can, and moreover the heavy fuel oil required by many types of Diesel engines must be of the highest grade. If a type of Diesel engine, to yield moderate power and speed in the average cargo steamers, were to be evolved to run on second grade bunker oil, and if necessary on such oil plus from 30 to 40 per cent. of pulverised coal, some relief would be afforded to the war problem of rationing the available oil supplies to essential needs.

Owing to the sea-carrying trade having been stagnant in the past two or three years, the demand for fuel has not been proportionate to the increase of tonnage. When healthy and normal conditions of employment of ocean carriers prevail, an increase of fuel requirements will necessarily result. It is possible, however, that some of the tonnage built during the war and at present unemployed may not need to be replaced. The great disturbing factor of the war renders it difficult to gauge what otherwise would have been the present-day normal relation of quantities, as between coal and oil supplies as ships' fuel. Generally speaking, however, it may be said that oil has come into use (including motor ships) for 27 per cent. of the world's merchant shipping, with very little effect on the production and distribution of coal, although otherwise coal might have shown an increase. To some extent new coal developments were checked during the war, and therefore but for the relative abundance of oil, the world might have been faced with a fairly severe stringency of fuel supply, with consequent increase of price, till the shortage could be overtaken. The world's merchant shipping tonnage pre- and post-war may also be glanced at in the fuel connection. In the three years' immediately before the war the world's merchant ships numbered about 30,000, with a tonnage approaching 50,000,000 tons. British ships (excluding those of overseas dominions) accounted for about 9000, and a tonnage of about 19,000,000 tons, or nearly 40 per cent. of the world's total. In the three years 1921, 1922 and 1923, the averages are, approximately: total number of ships about 33,500, tonnage about 64,000,000 tons, the British figures being about 8800 and tonnage of 19,300,000 tons (approximately); the British percentage of the total tonnage being about 30 per cent.

The number of ships thus shows a fairly large increase. The very considerable increase already made in oil bunkering, which must inevitably continue as oil is the superior fuel for marine purposes, raises many points that require careful consideration.

So far as facilities for storage and distribution of fuel oil at bunkering stations on the principal ocean routes are concerned, it may be assumed that what has been done already, and will yet be done by British enterprise, will maintain a strong position.

We must recognise, however, that whilst the British Empire is self-supporting at so many important points in regard to coal supply, and has a considerable exportable surplus, we are obliged to import by far the greater part of our oil not only at U.K. ports but at most of our overseas ports as well. In normal times in the ordinary course of trade the world's oil supplies, from whatever countries they are derived, find their way to the various points of requirement or centres of distribution.

The attention which Great Britain has given to the development of supplies of oil may be gauged in many ways, but more particularly by the capital invested in oil companies operating in British possessions and in certain foreign countries. There is much reason for encouragement in what has been and is being done.

Incidentally some evidence of British enterprise and influence in oil production, manufacture and distribution may be deduced from the growth in the membership of the Institution of Petroleum Technologists, referred to at their recent annual dinner. The Institution was founded in 1913 by 29 persons; by September, 1915, the membership had grown to about 190; at the present time it approaches 700. The members of the Institution are engaged in the technical and scientific branches of the oil industry in many parts of the world. Petroleum technology embraces oil geology, chemistry, engineering, field work, drilling, refining, transport, distribution, etc. Whilst the American continent north, central and south, is likely to remain for any period that we can foresee at the head of the world's oil production, future developments in Asia and elsewhere are likely to be in spheres where Great Britain may expect to possess an important and increasing share of influence. The further development of Eastern fields will also have its effect in the direction of meeting market requirements by "shorter hauls," *i.e.*, some reduction of the distance of transport from oil fields to points of distribution. A word or two may be said here as to the recent tendency to provide oil-refining facilities in the United Kingdom, Australia and elsewhere, which in present circumstances are fed mainly by imported oil. The U.K. imports a large quantity of crude oil from Persia for refining, and cargoes have been brought in from Venezuela, Mexico and Trinidad. The commercial considerations that determine such

a policy are fairly well known, viz., production costs *i.e.* of fuel, labour, machinery, transport, etc.; but especially whether there is an adequate market demand for oil products in the country where the refinery is placed, or in more or less neighbouring countries, economically accessible to delivery of products by tank steamers. An oil refinery situated at a consuming, rather than a producing centre, may possess a special advantage, commercial and national, viz., that it is less dependent upon only one source of supply of its crude oil. In exceptional circumstances of war or other emergencies, various expedients have to be adopted, *e.g.*, the production and utilisation of substitutes for natural petroleum, the development of home production of crude oil from coal, shale, etc., or the utilisation of such imported crude oil as may be available in addition to or in place of the normal supplies. In such circumstances the existence of refining capacity at or near the points of consumption or distributing centres would be of the highest value.

As regards normal commercial requirements of fuel oil the foregoing review of the present situation is intended to show that the transition from coal to oil is likely to continue at a relatively rapid rate but necessarily step by step with the provision of facilities for distribution and transport.

A detailed consideration of how naval, military, air service, and essential civil requirements of petroleum products would have to be met, if unhappily at any future time war on a great scale should again come upon a number of the nations of the world, lies beyond the scope of the present paper.

Few, if any, persons will be bold enough to predict whether the goodwill of the nations and international peace organisation will, as must be hoped, indefinitely postpone the evil day; or, if not, when and where war may be likely to occur; or, in that event, what the groupings of belligerents may be; and how they may be situated respectively, favourably or unfavourably, as regard control of oil supplies and its transport overseas. In any period to which we can look forward, in which war might unhappily occur, and whatever developments of methods of warfare may be brought about by chemical research or mechanical inventions, petroleum in the form of motor spirit, lubricating oils and heavy fuel may be expected again to play a considerable and essential part. The measures that were necessary in the late war would again be necessary in some degree or other, according to circumstances, on the part of all concerned, *e.g.*, the prudent maintenance of reserves, economy in use, rationing of available supplies, utilisation of substitutes and the development of both domestic and all other possible resources.

DISCUSSION.

Mr. Herbert Barringer said he was sure all the members regretted the absence of Sir Frederick Black, because he was certain that the author would have had something to say in addition to his paper which would have proved most interesting. The question was often asked why Deisel engines were not used in the Navy. Admiral Dixon gave a very good reply to that at the Annual Dinner, when he stated that each unit of power (4) in the *Hood* was something like 33,000 h.p. Taking one unit of a Deisel engine as 1000 h.p., it would readily be appreciated what an immense number of cylinders it would be necessary to have on board ship to produce that amount of power. He hoped engineering material and the Deisel engine would be improved so that at some time in the future it might be possible to produce units of the power required. In any case it would have to be through an electrical drive or some other means of that kind, because it would be impossible to drive with all that number of cylinders on to any number of shafts. The paper was full of very valuable statistics, and he would value it very much as a record. He had no doubt that Sir Frederick Black would be informed that his paper had proved of great interest and that all the members very much regretted his absence through illness.

Mr. A. Beeby Thompson said he was sure all the members sincerely regretted the absence of Sir Frederick Black. On the question of storage, he would like to refer to the unnecessary amount provided for events which ought to be avoided. The best, cheapest and safest storage for oil was where it occurred in the earth. At the present time he believed hundreds and hundreds of 55,000 and 70,000 barrel steel tanks were being built in America, and which he was told would never be used more than once. The oil was taken out of the ground at a greater speed than it could be despatched from the field and had consequently to be put into tanks, which cost erected about 60 cents. per barrel capacity. The storers expected to recover the cost of providing this storage from the purchasers in the future when the flush production fell and the price of crude rose. Such surface stock was very wasteful, as the annual losses reached 2 or 3 per cent. in volume, and might far exceed that figure, while the value of the product lost was usually 8 to 15 per cent. Until, however, some more rational method could be introduced of operating on oilfields he was afraid no machinery existed for stopping that waste, particularly in new

fields where small plots were competitively developed at a terrific rate, far in excess of the market and pipe-line capacity.

Mr. Herbert Barringer said that Sir Frederick Black's was the last paper to come before the Petroleum Section. He thought the Section could congratulate itself on having held a very successful Congress. The meetings had been well attended, at least 50 or 60 being present at each session, and the discussions on the papers had been quite as lengthy as those in any of the other Sections, with the exception of the two papers presented that afternoon. He therefore thought the Petroleum Technologists were to be congratulated on having maintained their high position. He was quite sure that the papers and the discussions would form a very valuable part of the Proceedings of the Congress when they were published, and that they would rank in interest with any of the papers that had been submitted to the other Sections of the Congress. He thanked the members for the way in which they had attended the meetings, and thus kept the name of the Institution well before the public.

The meeting then terminated.